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GUIDELINES FOR THE INTEGRATION OF WILDLIFE AND HABITAT EVALUATIONS WITH ECOLOGICAL LAND SURVEY

Wildlife Working Group
Canada Committee on Ecological Land Classification

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The Wildlife Working Group of the Canada Committee on Ecological Land Classification (CCELC) was originally formed in 1980 as one of several active working groups under the CCELC umbrella. Its primary aim is "to encourage and facilitate the development of effective and standardized methods for wildlife habitat classification and evaluation, as well as to further the integration of wildlife values within an ecological land survey framework." Membership in the Working Group is from all regions of Canada, and includes a broad range of professional expertise and interest in natural resources research and management. Participation in Working Group projects are largely voluntary in nature.

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Preface

Wildlife and habitat managers, as well as managers in various other natural resource fields, are increasingly faced with complex decisions along with growing mountains of data and information. Our progressively specialized and narrowly focused approach to wildlife and habitat management results in fragmented perceptions and understanding of the larger systems at work in the natural world. To use an old cliché, "we no longer can see the forest for the trees." We have trouble recognizing and effectively addressing big problems (root causes) because the smaller, detailed problems (mostly symptoms of the bigger problems) keep diverting our attention.

We need to be able to develop perspectives on larger, more holistic entities so as to better understand and manage smaller, individual components. Ecological land survey (ELS), both as concept and as method, offers us this potential within the field of wildlife and habitat management. The emphasis in ELS is on identifying, describing, and interrelating physical and biological components of the environment from a hierarchical perspective of ecologically functional and geographically recognizable entities or wholes. This is really a landscape-based approach to ecology.

Wildlife and habitat managers are particularly compelled to try to apply integrative and holistic approaches, such as ELS, because they are attempting to manage wild vertebrate populations having very complex species/habitat relationships over often large areas. Over the past 20 years, there have been greatly expanded efforts to identify and quantify wildlife values in the context of resource developments and land use pressures that increasingly impinge on, and alter, wildlife habitat.

In this respect, wildlife and habitat professionals have expressed the need for a manual to guide in the collection, analysis, and presentation of wildlife resource data and information within an ecological, land-based framework. This guidelines manual is a first attempt to meet this need. The primary content of the manual is presented in Part A, chapters 1 to 4. Chapter 1 presents an overview of the historical development, rationale, and general methods of ELS. Much of the early biophysical and ELS work had little, or no, wildlife content. However, this has gradually changed over the years to the point at which ELSs are, in some instances, a primary vehicle for identifying and evaluating wildlife values. The background information in Chapter 1 provides an important backdrop to the more detailed examination, in Chapter 2, of how to incorporate wildlife objectives and measurements within the survey proposal and land classification phases of ELS. For specific projects, there is an unlimited range of detailed data collection possibilities. However, Chapter 2 focuses on general methods, broad categories of data collection, and basic principles--factors that should help to ensure an effective, integrative, and ecological approach to the survey.

Chapter 3 focuses on the evaluation, or interpretation, phase of ELSs and wildlife habitat inventories. It examines generic kinds of wildlife assessments and reviews structured interpretation techniques (land/wildlife relationship models) that have been developed and used in various parts of North America. Again, the focus is on basic concepts and methods that have the flexibility to be adapted to a variety of specific project requirements. Creative adaptations of these guidelines will be required to meet specific project conditions and needs.

Chapter 4 concludes the primary content of the manual by examining the foregoing subject matter from the perspective of overall client information and wildlife and habitat resource

management needs. The main justification for any wildlife survey or habitat inventory is the provision of information, suitable in content, quality, and format, to assist in decision-making. If the manager does not obtain this information in a timely and readily understandable fashion, large volumes of inventory data and analysis will be for naught. Throughout the manual, numerous references are made to the critical importance of having wildlife and habitat assessments structured around, and driven by, objectives that clearly reflect client information needs. To be effective, the final inventory project deliverables must package summary information in a way that makes it readily useable by wildlife and habitat resource managers and other decision-makers.

In Part B, chapters 5 and 6 provide important supplementary information to the core chapters. Chapter 5 provides an overview of automation technologies, such as computer-supported data base management, mapping, and modelling, including geographic information systems. These technologies can be invaluable, cost-effective tools to assist in the evaluation phase of wildlife and habitat resource surveys, as well as data maintenance, update, and display. They can also be used to structure and build ecologically oriented land classifications. Chapter 6 provides a comprehensive review of basic ecological principles which are relevant to the development of application methods and guidelines as presented in this manual.

H.A. Stelfox
Past Chairperson
Wildlife Working Group

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A number of people have provided advice and encouragement towards the development of these guidelines over the past several years. The idea for a manual of guidelines was first raised at the Wildlife Working Group Workshop held in Banff, Alberta (March 1982) – a number of the workshop participants provided valuable input to the early conceptual planning for the manual. Participants in the Wildlife Working Group Workshop held in Mont Ste-Marie, Quebec (September 1985) reviewed and commented on a very preliminary draft of the manual. Members of other CCELC working groups and various provincial and territorial agencies have also supported the initiative. Most recently, Dennis Demarchi (British Columbia Wildlife Branch) and Rick Bonar (Weldwood of Canada Limited) provided comprehensive review comments on a near-final draft.

Throughout the preparation of these guidelines, Ed Wiken and staff of the CCELC Secretariat have provided considerable technical, coordination, and financial assistance to the editors and authors. Appreciation is also due to the employers of the editors and authors for permitting their staff to participate in this project.

Financial and technical support provided by Gerry Lee, Habitat and Land Use Division (Canadian Wildlife Service) and David Neave, Executive Director (Wildlife Habitat Canada) have enabled this several-year endeavour to come to fruition.

Part A:

Integrated land/wildlife surveys and management

1. Ecological land survey: background and general approach

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Definition of ecological land survey

Ecological land survey (ELS) is an interdisciplinary approach to gathering and interpreting environmental data. Under this approach, the environment is considered to be composed of natural or man-modified ecosystems that are land based. In an ELS context, "land" is referred to in the holistic sense as being composed of a complex and interconnected web of abiotic and biotic ecological components, including bedrock, landforms, soils, water, climate, vegetation, and wildlife.

Rationale

The increasingly complex fields of natural resource planning and management necessitate a system of land survey that promotes a comprehensive understanding of landscape areas as dynamic ecosystems composed of interrelated physical and biological components. The use of a single land resource may disturb landscape processes and, as such, impact on other land resources. In recent years, this simple premise has been increasingly recognized and confronted by resource management and planning agencies. Such commonly referred to terms as "integrated management planning" and "multiple use" attest to this recognition. Effective management and planning within an integrated management forum demand a system or framework for resource information. ELS is a means of simplifying and organizing a very diverse body of data in a way that allows resource managers to address complex land use/resource development issues, for both long-term planning and day-to-day management.

The interdisciplinary approach of ELS has many practical advantages over the conduct of several unidisciplinary surveys (Wiken 1980).

- An integrated approach reduces redundant data-gathering activities. As such, resources normally spent on the duplication of what others have done can be redirected to enhance the baseline study.
- The more stable aspects of the environment (e.g., landforms and soils) are stressed in the data collection phase, so as to maintain the usefulness of the baseline study over the long term.
- A team approach to data collection avoids the proliferation of discordant map lines for, and descriptions of, areas having similar environments.
- The data are collected in the context of interacting landscape processes and can therefore be used to predict overall ecological responses to management prescriptions.
- The report(s) and map(s) are amassed into one convenient package for reference and access.
- A diverse range of environmental data is simplified into one common framework.
- The costs/benefits of a single interdisciplinary survey often outweigh the cumulative costs/benefits of a number of unidisciplinary or thematic surveys.

The decision of whether or not to apply an interdisciplinary, ecological approach to land survey depends on the particular needs of the client or user. In some instances, the advantage of conducting a single-theme approach may outweigh that of an integrated survey. Examples of cases wherein a single-theme mapping might be more appropriate than an interdisciplinary survey are as follows:

- The user may require specific, detailed information on a single resource theme and may not necessarily be interested in predicting overall ("ecological") responses resulting from the description of landscape processes (e.g., an engineer's requirement for detailed soil texture information for road construction).

- When budgets do not allow a sufficiently detailed classification of a number of different resource themes, it is sometimes most convenient to collect thorough data on the most important resource. A "watered-down" ELS product may be less useful than a detailed single-theme survey.

- In certain landscapes that are especially homogeneous with respect to vegetation and terrain, the utility of ELS for wildlife resource evaluation tends to decrease (e.g., extensive tracts of black spruce or jack-pine forest). From a wildlife perspective, the vegetation resource becomes very dominant in terms of the evaluation of land importance in such situations. Therefore, it may be more cost-effective to expend resources on detailed vegetation classification and mapping than on ecological integration.

Recent technological developments in the field of geographic information systems (GIS) have increased the land manager's spatial data display, overlay, and analysis capabilities. Special care, however, should be taken to avoid the temptation of rapidly overlaying several resource themes of varying mapping scales to produce a "quasi" ELS product.

History of development

Ecological regionalization of land in Canada goes back several decades and includes a number of programs at provincial/territorial, national, and federal levels of jurisdiction. Some examples of regional programs include the biogeoclimatic classification of Krajina (1965) in British Columbia, forest land classification by Loucks (1962) in the Maritimes, ELSs in the Yukon (Oswald and Senyk 1977, Wiken *et al.* 1981) and land classification of the mountain national parks (Holland and Coen 1983). Smaller-scale ecological regionalizations have also been conducted at the national level, including Rowe's (1972) forest regions of Canada.

Vital to the development of guidelines for integrated land survey in Canada has been the formation in 1976 of the Canada Committee on Ecological Land Classification (CCELC). Further details on the history of development of ELS and the CCELC can be obtained in Subcommittee on Bio-physical Land Classification (1969), Canada Committee on Ecological Land Classification (1977, 1979a, 1979b), Wildlife Working Group (1980, 1984, 1988), and Ironside (1989).

General methods

The basic process of an ELS consists of three major steps, as illustrated in Figure 1.1.

Survey proposal

This first step consists of interaction and discussion between the surveyors and the survey proponents/users. The primary objective is to set study goals and terms of reference in such a way that the perceived needs of the users can be effectively and realistically met. This is best achieved by:

- identifying user needs, work to be done, and desired end products;

- assessing the mandate and purpose of the work;

Figure 1.1:
Three sequential steps in conducting an ecological land survey

1. Survey Proposal
STUDY OBJECTIVES
- identify user needs, work to be done, and desired end-products;
- assess mandate and purpose for the work.
TERMS OF REFERENCE
- establish survey constraints — available time, money and manpower;
- set goals to ensure that the detail, timeliness and scope of the ecological data are appropriate to the user;
- develop a general survey plan and select a field team leader.
2. Ecological Land Classification
PREFIELD PREPARATION
- review existing data;
- prepare a field sampling plan and timetable;
- select and consult field team;
- obtain work materials and field support;
- choose field description standards;
- begin analysis of remote sensing imagery and preliminary delineation of map unit boundaries.
FIELD INVESTIGATIONS
- overview study area;
- collect biological and physical data;
- check and adjust map unit boundaries.
POSTFIELD ACTIVITIES
- analyze/synthesize the collected data;
- organize results and finalize the ecological classification.
3. Ecological Land Evaluation
PRESCRIPTIONS
- develop ecologically based Plans or strategies;
- formulate appropriate management actions;
- identify resource use conflicts;
- develop a monitoring program.
INTERPRETATIONS OF DATA BASE
- evaluate/interpret data to prepare maps or texts on themes such as resource capability, environmental impacts, ecosystem resilience, flood-prone areas, areas subject to mass movement, potential for recreation, etc.

- establishing the constraints of the survey (i.e., available time, money, and manpower);
- setting goals to ensure that the detail, timeliness, and scope of the ecological data are appropriate to the user; and
- developing an integrated survey and selecting a field team leader.

In the survey proposal, a representative of each participating resource discipline must provide input concerning integration requirements. Effective communication at this early stage often sets the template for the remainder of the survey.

Ecological land classification (ELC)

This is the data-gathering phase of the ELS. It is concerned primarily with partitioning the study area into areas of similar environment and classifying the units based on physical and biological characteristics. As it is not feasible to collect all possible types of land data, the techniques used rely on the rapid identification and analysis of sets of data that are elemental to the classification and mapping of land ecosystems (e.g., soils, landforms, and broad vegetation types). This is achieved via remote sensing analysis (usually using Landsat images and aerial photographs) combined with variable-intensity field checking.

Remote sensing and "image analysis" yields the preliminary data sets on the physical and biological land characteristics and initially stratifies the study area into "ecologically significant" polygons or map units (Walmsley *et al.* 1980). The remote sensing analysis is supplemented and refined, prior to field checking, through a review of available literature relevant to the study area. The subsequent field checking is designed to verify the accuracy of the original map unit boundaries, as well as to obtain certain forms of data (e.g., soil, vegetation, and wildlife) that are not readily attainable by in-office techniques. Map unit boundaries are often modified as a result of field checking.

The number, size, and descriptive detail of map units within a particular study area vary according to the user's needs. The ELS approach has accommodated this variation through the evolution of a hierarchical system of land classification and mapping. Table 1.1 presents an overview of the various levels of generalization within this hierarchy and some common benchmarks for their recognition. As one descends through the hierarchy, map units become smaller, the variability in characteristics decreases, and the descriptive data become increasingly specific. Associated with changes in mapping scale are also changes with respect to the applications of ELS to resource managers and planners. Broad orders of resource management and planning within the ELS hierarchical framework are shown in Table 1.1.

The following are some broad categories which are used to characterize individual map units.

- Components present--The six major components that can be used to characterize a land ecosystem are landforms, soils, water, climate, vegetation, and wildlife.

- Abundance--This refers to the relative quantities of components associated with each map unit. Examples include the relative percent cover of each vegetation grouping, plant biomass production, volume of water flow, and wildlife species abundance.

- Pattern--This is the arrangement of components either vertically or horizontally, within a map unit. Vegetation interspersion measurements are one example of an index of the mosaic or pattern of vegetation within a land unit. For wildlife, pattern could refer to broad geographic and elevational preferences or to patterns of use of layers of vegetation within a particular cover type.

- Ecological relationships--An integrated ecological land unit is characterized by the relationships between each of its various components. For example, vegetation composition and cover will vary depending upon soil texture, soil nutrients, soil water, aspect, etc. These relationships are often complex, but are predictable and can be used to extrapolate knowledge for areas that have been visited to unvisited areas which are identified as similar through remote sensing techniques.

The final activity of the ELC is to present the collected data in a textual, tabular, cartographic, and/or computer format. The

Table 1.1:
Levels of ecological generalization proposed by the Canada Committee on Ecological Land Classification (adapted from Wiken 1986)

Level of generalization (common map scale*)	Definition	Orders of planning	Examples of common benchmarks for recognition					
			Geomorphology	Soils	Vegetation	Climate	Water	Fauna
Ecozone (≥1:15 000 000)	An area of the earth's surface representative of large and very generalized ecological units; characterized by interactive and adjusting abiotic and biotic factors	International, national, and provincial						
Ecoprovince (1:15 000 000 to 1:5 000 000)	A part of an ecozone; characterized by major assemblages of structural or surface forms, faunal realms, and vegetation, hydrological, soil, and climatic zones	National and provincial	Assemblages of regional landforms	Soil order	Broad physiognomic types (e.g., deciduous trees vs. evergreen shrubs vs. grass)	Macroclimate	Major watersheds	NA
Ecoregion (1:3 000 000 to 1:1 000 000)	A part of an ecoprovince; characterized by distinctive ecological responses to climate as expressed by the development of vegetation, soil, water, fauna, etc.	Provincial and regional	Large-order landforms or assemblages of regional landforms	Great groups or associations thereof	Plant regions or assemblages thereof	Meso- or small-order macro climate	Large water basins	Assemblages of wildlife communities
Ecodistrict (1:500 000 to 1:125 000)	A part of an ecoregion; characterized by distinctive assemblages of relief, geology, landforms, soils, vegetation, water, and fauna	Subregional	Regional landforms or assemblages thereof	Subgroups or associations thereof	Plant districts or assemblages thereof	Meso- or large-order micro climate	Drainage pattern; water quality	Wildlife community or some specialized habitat
Ecosection (1:250 000 to 1:50 000)	A part of an ecodistrict; characterized by a recurring assemblage of terrain, soils, vegetation, water bodies, and fauna	Community	Assemblages of local landforms or a local landform	Families or associations thereof	Plant associations or assemblages thereof	Large-order to small order micro climate	River reaches, lakes, and shoreland	Specialized habitat within a community or a lower-order community
Ecosite** (1:50 000 to 1:10 000)	A part of an ecosection: characterized by a relative uniformity of parent material, soil, hydrology, and vegetation	Detailed	A local landform or portion thereof	Soil series or associations thereof	Plant association or community	Small-order micro climate	Subdivision of above	Portions of a community or total habitats of some small species
Ecoelement (1:10 000 to 1:2500)	A part of an ecosite: characterized by uniform soil, topography, vegetation, and hydrology	Site-specific	A local landform or portion thereof	Phases of soil series or a soil series	Parts of a plant association or a subassociation	Small-order micro climate	Section of small streams	Home ranges of some small species, such as small mammals and songbirds

* Map scales should not be taken too restrictively, as they will vary with the setting and objectives of the survey.
** More so than others, this level is frequently subdivided into phases to indicate a passing or temporary stage (e.g., seral).
NA Not applicable

exact presentation format to be used depends on the needs of the user and should be specified during the survey proposal. However, it should be structured to permit retrieval via single or multiple descriptive characteristics which will make it extremely flexible for the ecological land evaluation.

Ecological land evaluation

Once the ecological data have been collected and organized in standardized formats, the third and final step of the ELS is to convert the data into more usable forms of information. This step of the ELS is tailored towards the interpretation and analysis of the land classification data. Evaluations are conducted in support of specific information or decision-making requirements. Example evaluations include land capability and land suitability for wildlife, environmental impact assessment, and ecosystem sensitivity. Extractions from the data base can also include single theme maps, such as sites having a high percentage of sedge cover, or multiple factor maps, such as all areas that have a combination of a particular vegetation cover, elevation, aspect, and slope. Such a combination may describe excellent summer range for a species, and the wildlife manager may wish to know the location and extent of similar habitats within a particular area.

ELS is predicated on land systems relationships. It therefore allows users to predict land systems responses. An ELS map unit is characterized not only by the abundance and pattern of its resource components, but also by the relationships or ecological processes that occur between components (e.g., vegetation succession sequences on different terrain types). These processes are observed and described during the ELC step. This information is thus made available to wildlife and habitat managers, who can then use it to predict responses of particular species or habitats to specific management actions.

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2. Wildlife-enhanced survey proposal and ecological land classification

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General considerations

Until recently, wildlife resources have received little in the way of serious attention as a major component of ecological land surveys (ELSs). Many past resource surveys or inventories either have ignored wildlife completely or have incorporated wildlife as an add-on, subsequent to the completion of the ecological land classification (ELC) step. Hydrological and climatic components have also received limited representation from land classifications that have traditionally emphasized soils, landforms, and vegetation (Stelfox 1983). However, a general recognition of the need for a more holistic approach to land management more recently has led to an increased integration of hydrologic, climatic, and wildlife values.

Wildlife resources have been difficult to address in the context of ELS for the following reasons:

- Many wildlife species are highly mobile and use a wide range of landscapes in time and space.
- Wildlife populations can fluctuate widely in total numbers over time.
- Wildlife are relatively difficult to observe, particularly using remote sensing.
- A high percentage of past wildlife surveys and research has not included habitat-based assessments; thus, relatively little was known of wildlife use as a function of landscape ecosystems.

Regardless of some of the problems mentioned above, most wildlife species can be effectively correlated with physical and biological attributes of the land. These same attributes are often also meaningful to other resource interests, such as forestry, agriculture, and mineral extraction (Stelfox 1983). By considering wildlife as a component of a mapped land unit along with those components of interest to resource users, a direct management link is established between wildlife and the land. Finally, in the last decade or so, there has been an increased emphasis on research into wildlife/habitat relationships. As this body of knowledge continues to grow, so will the effectiveness of the integration of the wildlife component into ELS.

Two obvious questions are as follows:

- **When** should the wildlife component be incorporated into ELS?
- **How** should wildlife values be incorporated?

These questions can best be answered within the context of the first two major steps of an ELS.

- *Survey proposal*--Effective integration of the wildlife component requires its consideration at the earliest stage in development of a survey proposal (i.e., during the establishment of survey objectives).
- *Ecological land classification*--Wildlife data should be incorporated as part of the ELC and mapping base. Such wildlife data may be treated as "diagnostic" or "characteristic" of the map units.

Techniques, logistics, and concerns associated with incorporating the wildlife component into each of these steps are presented in the following two sections.

Survey proposal

As the ELS process has evolved and wildlife has become an increasingly recognized component, it has become apparent that there must be direct involvement of wildlife personnel at the earliest stages of planning (i.e., during the survey proposal). Wildlife managers (Prescott 1980) and resource planners (Seel 1984) have recognized and expressed this need. Some advantages of early representation of the wildlife component are as follows:

- A base of communication is established between the scientists associated with the various ELS components. In an ideal situation, this could extend throughout the entire process. Seel (1982) noted that the ELS process forces scientists working within the roles of the system, even prior to any actual field work, to develop a consensus on the philosophical, methodological, and technological parameters which will guide their collective efforts. This communication leads to an increased understanding of landscape processes and their associated impacts on wildlife habitat availability and use.

- Early discussion increases the likelihood that the client's wildlife-related survey objectives can be realistically met. Specific considerations should include scope, level of detail, time frame, and scheduling of the survey.

- It improves the chances of a logical and feasible progression between the data collection, evaluation, and final reporting (i.e., early clarification of how the type and detail of data collected can be evaluated to meet the client's desired end products).

- Early discussion between members of the integrated survey team provides each member with an idea of the specific logistics and limitations of the procedures of the others. Thus, realistic accommodations and compromises can be reached to best serve the overall objectives of the survey. wildlife are a mobile resource with seasonal land preferences that often must be measured using specialized and time-specific procedures. Hence, the timing of wildlife field data collection does not always integrate smoothly with other data collection, and these constraints must be clearly identified during the survey proposal.

As part of setting the survey terms of reference, it should be ensured that the level of detail, scope of the subject matter, and time frames and scheduling of data collection will meet the user's wildlife-related information needs. Some considerations regarding the terms of reference are discussed in the following:

Types of wildlife and habitat data required

The types of wildlife data collected must be closely related to the end user's needs. The user has a choice of a range of data types depending on specific management or planning needs. Table 2.1 outlines the basic approaches and types of wildlife data that may be collected in support of subsequent evaluations. There are three basic approaches to wildlife data collection: individual species, wildlife communities, and wildlife habitats. One or all of these approaches can be applied, depending on specific management requirements.

Selection of featured species

The practical considerations of available time and money generally do not allow the wildlife manager or planner to measure and monitor population status for all, or even most, of the wildlife species in a study area. It is usually

Table 2.1:
Wildlife data collection approaches and measurements that may be used to sample wildlife within an ELS framework (adapted from Jones 1986)

Data collection approach	Measurement type
Individual species	· Presence/absence · Relative abundance (indices) · Absolute abundance (densities) · Population structure (age/sex ratios) · Productivity (recruitment rates) · Population condition · Presence/absence by habitat type
Wildlife communities	· Species richness · Presence/absence by habitat component · Community abundance · Biomass · Species similarities · Species diversity and habitat use diversity · Species overlap
Wildlife habitat	· Food item abundance · Vegetation interspersion · Habitat diversity · Vegetation chronosequence and phenology

necessary to select a group of species that will reflect the management and/or planning concerns of the user. These have been variously termed "featured species" (Harcombe 1984), "priority species," or "management indicator species" (Salwasser and Unkel 1981). The criteria for choosing "featured species" will vary depending on the desired applications of the ELS (Table 2.2 summarizes some potential criteria). Examples of modelling systems used for selecting featured species can be obtained from Green *et al.* (1984, 1986).

Level of survey detail

Level of survey detail includes both the scale of mapping and classification and the level of effort expended for measuring wildlife populations and habitat use. The choice of mapping scale will determine subsequent levels of planning and/or management, as well as the range of species to which the ELS can be applied. If, for example, a wildlife manager is interested in assessing temporal response of vegetation growth and wildlife use after clear-cut logging, then it will be necessary to select a scale of mapping and classification that is applicable to the "plant association" or ecosite/ecoelement level of description.

It is also important that the manager ensures a level of field data collection that will support all required land evaluations. Considerable attention should be given to establishing the lowest-level (most detailed) common denominators required for the wildlife inventory to support all analyses. For example, if the relative forage biomass of all representative plant associations is to be determined, then it should be established during the survey proposal what levels of

Table 2.2:
Criteria that may be used to select management indicator species for an ELS

Management theme	Detailed criteria
Sociopolitical	• Public appeal • Relative abundance status • Degree of management concern • Regional significance
Economic	• Supply/demand • Licence sales • Subsistence value • Commercial value
Recreational	• Public appeal • Accessibility to public • Domesticity levels • Relative abundance • Demonstrated public use--consumptive or non-consumptive use (e.g., hunting licence sales, photographic opportunities)
Ecological	• Endangered, threatened, or vulnerable status • Special habitat needs that may be affected by management actions • Species whose population fluctuations will reflect or influence those of a range of other species (i.e., ecological indicator species) • Species that depend on early or late successional vegetation • Ease of monitoring (observability, abundance) • Degree to which species is cyclic

sampling will be necessary to yield a defensible comparison between associations.

Level of detail of field sampling should be related largely to the required precision or accuracy of resultant evaluations. If the ultimate end product is a four-tier rating of land unit importance (e.g., high, medium, low, nil), then exhaustive and precise field sampling may not be required. The summarized results of less detailed sampling may be used as one of a number of information sources to support subjective assessments of land unit importance.

Survey time frame

An ELC-based wildlife survey should be conducted for two or more years to allow for the variation in wildlife distribution that can result from fluctuating weather conditions. This is especially relevant in the case of an assessment of habitat use by ungulates, which can exhibit markedly different habitat use patterns during harsh versus mild winters. However, funding levels and time-frame limitations often require an ELS to be conducted in less than one full year. This is particularly true for large-scale surveys of

small areas (e.g., when ELS is used to assess environmental impacts of a proposed resource development site).

To ensure the optimum choice of sampling techniques relative to project timing, the particular applications and limitations of the various field data collection procedures must be understood. Consider, for example, an oil company that plans to link producing oil wells for a pipeline-gathering system and has been requested to conduct an ELS of the area to determine the most environmentally suitable pipeline placement pattern. The regional wildlife manager's primary concerns are for moose and furbearers, as the area is hunted heavily and encompasses two registered traplines. Budget constraints limit the field survey to four months, but the choice of season is flexible. In this situation, winter sampling by track counts and aerial surveying would allow objective data collection for both moose and most furbearers, whereas spring and fall sampling would be ample for moose (pellet counts/browse surveys) but not for most furbearers. Thus, the client must discuss these kinds of scheduling considerations with a wildlife biologist before the terms of reference are established.

A range of microcomputer-based project management software packages is available to wildlife and habitat managers planning implementing an ELS (see Chapter 5). These support technologies allow managers to more effectively coordinate and control the timing, sequencing, and budgeting of project tasks. Wheelwright (1986) reviewed current project management programs and available software packages. Table 2.3 illustrates how one particular system (Gantt chart) may be used to plan scheduling of the various aspects of an ELS. Such systems allow simulation modelling to determine relative costs/benefits of various scheduling and timing scenarios. They can also be used to identify critical paths and information transfer points to ensure that all tasks are appropriately sequenced and linked.

Integrating wildlife and habitat data collection with other data collection

The terms of reference should help to clarify the logistics of how and when the wildlife surveyor will be integrated with the rest of the ELS team, so that a proper scheduling of data collection and exchange of information and ideas will occur. Table 2.4 summarizes the relative pros and cons of conducting wildlife field surveys before, during, and after land classification and mapping.

If wildlife surveys must be conducted before the classification of land units, it is important for the wildlife biologist(s) to accurately reference the location of sampling sites and to document vegetation types at sample sites. This will ensure that the resultant wildlife data can be most efficiently integrated into an ELC "after the fact."

Wildlife surveys have been successfully conducted both during and after the classification of land units. The choice ultimately depends on the needs and resources of the particular client. However, it is important that there is at least some level of involvement of a wildlife expert during the land classification step. The wildlife biologist may influence the mapping of land units, but criteria for relatively stable features such as landforms and soils should have a primary influence on the location of map unit boundaries. The most useful role of the wildlife biologist is in ensuring that the land attributes required for subsequent wildlife evaluations are included and appropriately measured during the land classification. One example is the recording of deadfall and standing dead timber cover density values during vegetation descriptions. These "extra" habitat features can then be used for subsequent evaluations concerning species such as bears (e.g., "ant" logs) and cavity-nesting birds.

The inclusion of wildlife biologists in the ELC step also improves their understanding of the chosen mapping and classification

Table 2.3:
A hypothetical example of a Gantt chart that could be used to manage the phasing and scheduling of a 14-month wildlife-oriented ELS

	Apr		May		June		July		Aug		Sept		Oct		Nov		Dec		Jan		Feb		Mar		Apr		May	
	1	15	29	13	27	10	24	8	22	5	19	2	16	30	14	28	11	25	9	23	6	20	3	17	3	17	31	14	28	12	26
1 - Start project	—																														
2 - Establish objectives, scope, detail	—																														
3 - Select featured species (F.S.)		—																													
4 - Review F.S. habitat literature			—																												
5 - Identify diagnostic habitat attributes			—																												
6 - Collect existing land survey info.		—	—																												
7 - Delineate initial map unit boundaries			—	—																											
8 - Ground truthing					—	—	—																								
9 - Modify map unit boundaries							—	—																							
10 - Classify plant associations/units							—	—																							
11 - Construct map legend								—																							
12 - Calculate vegetation interspersion								—																							
13 - Write report								—	—																						
14 - Summarize wildlife survey info.									—																						
15 - Stratify/select sampling sites									—																						
16 - Train crews/data sheet prep.										—	—																				
17 - Conduct beaver/muskrat surveys												—	—																		
18 - Plan aerial surveys (ungulates)													—	—																	
19 - Fly ungulate aerial surveys															—	—		—			—	—									
20 - Interview trappers/locals																															
21 - Summarize and analyze winter data																							—	—	—	—					
22 - Assess land unit importance (modelled)																							—	—	—	—					
23 - Assess land unit importance (subjective)																							—	—	—	—					
24 - Write wildlife habitat report																							—	—	—	—	—	—	—		
25 - End project																															•

Table 2.4:
The primary pros and cons of conducting wildlife field surveys before, during, and after the ELC

Timing	Pros	Cons
Before	• Aids in stratification of habitat sampling • Reduces levels of field sampling required during ELC phase	• Lack of uniform vegetation classification for reference to point data • Lack of a geographical framework for stratifying sample surveys • Limits interaction between wildlife biologists and rest of the ELS team
During	• Maximizes input of wildlife information and expertise for land classification and mapping • Improves accuracy of collection of land/wildlife relationships data • Decreases overall field costs	• Lack of a completed vegetation classification within which to collect and summarize wildlife data • Map unit boundaries can change after ground truthing, hence some wildlife transect data can be lost • Tends to undersample ecotones and rare/unique vegetation, as ELC ground truthing concentrates on modal sites
After	• Finalized polygon designations provide a stable sampling stratification framework • A finalized vegetation classification improves summary and analysis of wildlife/vegetation relationships	• Increased expense associated with separate land classification and mapping and wildlife surveys • Limits exchange of information between wildlife biologists and remainder of the ELS team

concepts. This can then lead to improved wildlife habitat evaluations. For example, a clear understanding of the methods and limitations of the ELC vegetation classification allows wildlife biologists to more accurately and consistently assess wildlife/vegetation relationships.

Finally, a member of the ELC mapping crew should be included with the wildlife team (if the wildlife surveys are conducted separately from the ELC mapping) to provide advice on vegetation and land unit classification and mapping concepts and methods. This person may also be included in a training/ orientation session for technical wildlife staff.

Ecological land classification

The relative amounts of time and effort dedicated to tasks within the ecological land classification (ELC) will vary considerably between ELSs and should be tentatively assigned during the survey proposal. The

relative proportion of time required for field data collection will be reduced if previous inventory and research studies have been conducted in the mapping area. Similarly, detailed planning of the integration of the wildlife field component with other aspects of ecological data collection during the survey proposal will reduce pre-field preparation time. Other factors influencing relative time spent on pre-field preparation and field data collection are funding level, remoteness of the survey area, mapping scale, and the objectives, scope, and detail of the ELC.

Pre-field preparation

Pre-field preparation provides a framework for the collection and subsequent evaluation of wildlife and habitat data. Some of the primary tasks are outlined in the following.

Literature review

An important first step of the pre-field preparation is a literature review concerning the distribution, abundance, and ecology of the wildlife species of interest in the study area. Normally, management indicator species will have been chosen prior to this point. Such sources as existing surveys, site-specific environmental impact studies (government or industry), and species-specific research studies (government or university) should be accessed. The retrieval of wildlife habitat use data and information should be stressed during this review.

An attempt should be made to organize wildlife information by ecoregion or ecozone within the study area. Specific gaps in the inventory or research data base, by ecoregion, should be highlighted.

The most important aspect of a literature review for the wildlife component of an ELC is the retrieval of information that will aid in the selection and evaluation of specific habitat attributes. It may be useful to summarize wildlife habitat requirements by categories such as landform, climate, water, and vegetation features (Nietfeld *et al.* 1984).

Interviews with local/regional experts

Often considerable information on wildlife status, distribution, and habitat use is not in written form. Interviews with local trappers, naturalists, and long-time residents are useful for capturing this kind of information. Other sources include local conservation officers, regional wildlife biologists, technicians, and academics.

It may be useful to structure interview questions such that the relative importance of land attributes to wildlife can be assessed. For example, a survey of environmentally sensitive riverine habitats near a large urban centre might require baseline information on the relative importance of vegetation cover types to songbirds. In this instance, it would be very useful to provide one or more of the local bird experts (e.g., from a natural history club) with a listing of the major vegetation communities and ask them to rate each of these habitats as to their potential to sustain particular breeding birds.

Scheduling and timing of fieldwork

Much of the scheduling will have been initiated during the survey proposal. By now, it should have been decided whether the wildlife field data collection will occur before, during, or after the other data collection. However, it is still necessary to finalize the details of wildlife integration with the ELC field program and to construct a timetable of the tasks to be completed. Some of the types of questions that may have to be answered are as follows:

- What existing land data, maps, and remote sensing materials will be available to the wildlife biologist at the time of field sampling?
- What is the exact time frame for wildlife data collection?

Answers to these questions should be dealt with through discussions among members of the interdisciplinary ELS team.

Identification of diagnostic land attributes important to wildlife

Before delineating the preliminary map units using remote sensing procedures, it is useful to identify the relative wildlife significance of land attributes that could potentially be used to identify boundary lines. Land attributes that are important to wildlife populations can be broadly divided into soils, terrain, vegetation, hydrology, and climate.

Table 2.5 provides an example of a hypothetical biophysical mapping legend format for land attributes that may be used to assess the relative importance of map units to wildlife. Supplemental attributes are separated from diagnostic features. Diagnostic attributes are used in the actual delineation of map unit boundaries. Supplemental attributes are land features that provide additional map unit data and, in addition to diagnostic features, are useful for interpreting habitat quality and habitat use for a variety of wildlife species. Such attributes are not diagnostic of the map unit boundary and may not lend themselves to remote sensing identification and measurement.

In most cases it would be economically impossible to comprehensively inventory all of these parameters. The most applicable and cost-effective land attributes must be identified for inclusion within the ELS or wildlife habitat inventory. The diversity and detail of land attributes used to assess wildlife resource values will depend primarily on the objectives of the study, the scale of mapping (map unit size), and the wildlife species of concern, as discussed below.

The overall, or primary, management objective of the survey will often determine the selection of land attributes for wildlife resource evaluation. For example, if the primary objective was to predict and assess vegetation and wildlife responses to intensive timber harvesting activities, then a detailed plant association level survey with successional stage designations would be necessary. Conversely, if the primary objective was to support integrated land use planning decisions in a provincial or broad regional context, then a less-detailed forest cover classification would probably suffice.

Another example of the influence that specific project objectives have on selection of the most suitable land attributes is the basic choice of assessing inherent land capability versus current land suitability. These two concepts are discussed in detail in Chapter 3. A wildlife or habitat manager interested solely in inherent land capability would require information on vegetation potential, community type and chronosequence. If, however, the inventory stressed current habitat suitability, then a detailed classification and description of current vegetation features would be needed.

The potential number and detail of land attributes selected generally increase as mapping detail increases. As an example, aspect is known to be an important landform feature affecting the distribution and relative abundance of ungulates. At scales of 1:250 000 and smaller, it is difficult to assign aspect classes to map units because of their relatively large size and high degree of landform heterogeneity. However, at scales of 1:50 000 and larger, map units are small and physiographically simple enough that aspect becomes a characteristic (diagnostic) and measurable component.

Selection of land attributes will be influenced by the wildlife species of management concern. For example, snow depth is an important variable to measure for ungulates, whereas it probably would not receive consideration if breeding birds were the sole concern. There is, however, considerable potential for overlap of important attributes. For example, vegetation strata diversity is very important to both breeding birds and

Table 2.5:
A portion of a hypothetical ELC legend showing diagnostic and supplemental land attributes used to map and evaluate land unit importance to wildlife

Map unit symbols			Diagnostic features					Supplemental features				
						Aquatic features		Soil			Land disturbance	
Ecoregion	Ecosection	Ecosite	Surface materials	Slope class	Vegetation cover type	Form (dominant)	Density	Type	Texture	Moisture regime	Type	Level
Alpine (A)	A.1	A.1.1	Residual	8	Sparse evergreen shrub	Creek	Low	Brunisol	Fine	Mesic	Linear	High
		A.1.2	Residual	8	Open evergreen shrub	Seepage	Mod.	Podzol	Variable	Mesic	Areal	Mod.
		A.1.3	Residual	8	Open evergreen shrub	–	Nil	Regosol	Medium	Mesic	–	Nil
	A.2	A.2.1	Colluvial	7	Sparse evergreen shrub	–	Nil	Brunisol	Coarse	Xeric	–	Nil
		A.2.2	Colluvial	7	Closed mixed shrub	–	Nil	Brunisol	Coarse	Xeric	Areal	Mod.
	A.3	A.3.1	Glacial	6	Closed graninoid	Seepage	Mod.	Regosol	Fine	Mesic	Areal	Mod.
Subalpine (S)	S.1	S.1.1	Morainal	7	Open evergreen tree	Seepage	Low	Luvisol	Coarse	Mesic	–	Nil
		S.1.2	Colluvial	7	Closed evergreen tree	3rd order	Mod.	Luvisol	Coarse	Mesic	Linear	Mod.
Etc...												

most ungulates. For surveys that include a wide range of species, it makes more sense to emphasize those land attributes that are important to the greatest number and/or groups of species.

An essential first step toward selecting the most suitable land attributes is to conduct a review of the known habitat requirements of the species or species groupings (life forms or guilds) of concern. This review may be completed in the form of "species narratives" (Harcombe 1984; Nietfeld *et al.* 1984). This format summarizes pertinent details about the natural history of each species within a standard taxonomic classification framework. The following information categories may be considered:

- Taxonomy;
- Status and abundance;
- Optimal habitat;
- Special habitat requirements, such as for breeding;
- Territory/home range;
- Food preferences;
- Distribution or range maps; and
- References

Once the species narratives have been compiled, they can be used to prepare tabular summaries of key habitat requirements and other special ecological considerations for the chosen species. These summaries should conveniently illustrate the influences of a range of environmental attributes (e.g., landform, soil, climate, and vegetation) that have positive or negative effects on the primary life requisites of the species of concern. It can also be useful to include information concerning key factors known to limit the population of these species, such as minimum home range requirements, specific land use susceptibility, and special habitat needs (e.g., cliffs for nest sites, hedgerows, or fast-flowing streams).

After the preparation of key habitat summaries, the information must be organized in such a way that the most suitable land attributes can be selected logically and objectively. Table 2.6 shows one technique used for surveys of selected mammals in the Atlantic provinces. This system used a five-part rating of the strength or overall influence of the particular attribute on the species and then averaged these values for all species to come up with an overall index for each land attribute. This system may be adapted to suit any particular survey. For example, all ungulates could be lumped together to produce an overall rating. Alternatively, consideration may be given to the relative influence of attributes on feeding versus reproduction versus shelter requirements, with a weighted rating system to accommodate the relative importance of these primary life requisites.

The final selection of environmental parameters should be based on some compromise between:

- their overall usefulness in assessing wildlife habitat for the species identified--this can be achieved using a weighted ranking system; and
- the relative economics (cost/benefit) of incorporating a given environmental parameter into the study. In some cases, practical emphasis may have to be placed on parameters which can be remotely sensed or for which reasonable quantities of relevant data/information already exist.

Preliminary delineation of map units

Landscapes are initially subdivided based on the interpretation of aerial photographs or Landsat images. Visual interpretation of conventional black-and-white panchromatic photographs is still the most commonly used technique. However, recent advances in

Table 2.6:
Relative values of various habitat attributes that influence selected mammals in their choice of habitats (modified from Prescott 1980)

Influential habitat factors	Species or species groups											
	Shrews	Bats	Arctic hare	Beaver	Muskrat	Coyote	Black bear	Weasel	Otter	Lynx	Caribou	Moose
Abiotic												
Geology	0	1	0	1	2	0	0	0	0	0	0	0
Surficial materials	0	0	0	2	3	2	1	0	0	0	0	0
Soil type	1	0	0	2	2	1	0	0	0	0	0	0
Topography	2	1	4	4	4	0	0	0	2	1	3	1
Aspect	1	0	1	0	0	0	0	0	0	0	2	3
Slope	2	0	3	4	4	0	0	0	2	0	2	3
Drainage	3	0	0	3	4	0	1	0	1	0	2	2
Climate												
· season length	1	1	2	4	3	1	2	1	2	1	2	2
· wind	0	1	4	0	0	1	0	0	0	1	2	2
· snow	3	0	3	2	3	2	1	0	1	2	4	2
· rain	1	0	2	3	2	0	0	0	0	0	1	0
· temperature	2	3	1	4	4	0	2	0	3	2	1	1
Biotic												
Vegetation canopy												
· composition	3	2	3	4	0	1	1	2	1	2	1	3
· density	2	3	4	3	0	1	3	2	0	2	4	2
· height	1	0	2	2	0	0	0	1	0	2	2	2
Shrub layer												
· composition	2	0	4	3	0	1	3	2	0	3	3	4
· height	2	0	2	2	0	1	2	2	0	3	2	2
Ground cover												
· composition	4	0	3	3	4	0	2	2	0	2	5	1
· density	3	0	2	2	2	0	2	3	0	1	3	1
Invertebrates	4	5	0	0	0	0	2	3	1	0	0	0
Fish	0	0	0	0	0	0	2	0	5	0	0	0
Birds	2	0	0	0	0	2	0	1	1	2	0	0
Reptiles-amphibians	1	0	0	0	0	0	0	1	2	0	0	0
Other mammals	2	0	2	2	2	4	1	4	0	4	1	0
Human history												
· exploitation	0	0	2	3	3	1	1	0	4	4	5	4
· land use	2	2	0	2	3	3	2	2	1	3	2	2
Disturbance												
· type	2	3	3	3	3	2	2	1	3	3	3	3
· size	1	0	2	0	0	0	0	0	0	3	4	1
Vegetation diversity	2	1	1	3	1	2	3	2	1	2	2	2
Successional stage	2	0	2	2	2	0	3	0	0	3	4	2
Proximity to water	3	3	0	5	5	0	0	0	5	0	0	3

Strength of influence: 0 – none; 1 – very weak; 2 – weak; 3 – moderate; 4 – strong; 5 – very strong

Landsat digital image analysis and spatial data analysis support technologies are replacing or supplementing the traditional interpretation of aerial photographs (see Chapter 5).

Stable and recognizable diagnostic land attribute such as parent material, surface expressions, slope class and dominant vegetation cover will be used by the air photo interpreter as the primary guides for delineating preliminary map unit boundaries. It is suggested however that other land attributes also important to wildlife be considered in the delineation of mapped units. To facilitate this, a wildlife biologist should work with the air photo interpreter to point out additional features that could be considered in the preliminary land stratification. An example is aspect in mountain biomes, which strongly influences vegetation understory composition.

The wildlife biologist should refer to a list of influential habitat factors such as those shown in Table 2.6, and discuss with the air photo interpreter how some of these could be integrated into the preliminary land unit delineation process.

Finalization of wildlife sampling methods

General methods of sampling are usually identified in the survey proposal (e.g., winter tracking versus pellet counts versus aerial surveys). The details of the chosen sampling procedure should be finalized in this step. Are pellet count plots preferable to transects? Should rapid aerial waterfowl reconnaissance surveys be chosen over detailed ground counts in representative map units? Decisions made must satisfy survey objectives while meeting budgetary limitations and be tailored for integration with other ecological aspects of the ELC.

Selection of field sampling sites or locations

The field sampling strategy should be designed to verify or modify the preliminary ELC interpretations and to collect wildlife population and habitat use data that could not be obtained via remote sensing.

Verification and modification of preliminary map unit designations are accomplished primarily through the collection of soils and vegetation data by scientists who typically work as a team at the same site. Vegetation sample plots are generally established in homogeneous areas representative of the predominant vegetation and landforms of selected map units (i.e., normal or modal sites). As soil is not directly detectable through remote sensing and is usually correlated with landform and vegetation type, it is usually sampled at the site originally chosen for landform or vegetation characteristics. Wildlife values may be sampled at the same site or even in the same plot as the vegetation sample, but there are definite drawbacks to restricting wildlife data collection to only these sites:

- Ecotonal areas tend to be undersampled.
- Unique, but highly important, habitats are undersampled.
- Map unit boundaries often change following ground truthing and this can lead to the loss of representative wildlife samples for all map units.
- Finalized map unit and vegetation classifications are not available for use in sample stratification.
- Sample plot size and distribution for wildlife data collection may be at scales much different from those required for soils and vegetation data collection (i.e., larger area sampling is required).

It is recommended that the wildlife biologist conduct wildlife habitat use and availability sampling in the same areas and at the same time as the rest of the ELC ground truthing, when feasible. However, wildlife sampling has to take into account the nonstatic nature of the resource. More widespread and/or multiseasonal field assessments are usually

necessary. A combination that includes a sampling program with the rest of the ELC team and conducting specific "season-dependent" surveys (e.g., winter aerial surveys and spring pellet group counts for ungulates) represents the ideal situation. The final choice will be determined by the specific requirements and resources of the client/user.

The following points should be considered when selecting sampling locations or allocating sampling effort for a wildlife inventory within an ELC framework:

- The wildlife biologist should use available information to stratify sampling. Existing maps and reports dealing with surficial deposits, landforms, soils, vegetation, etc. can be examined to ensure that a representative sample of land attributes is achieved. Computerized area analysis software packages can aid such stratification.

- As full a range of natural and human-induced land attributes as possible should be sampled. Burns, avalanches, clearcuts, and pipelines should not be under-represented or omitted.

- The biologist should plan to sample pre-determined combinations of attributes (e.g., dry pine forests or south-facing colluvial slopes versus mesic pine forests on north-facing morainal slopes). At large scales of mapping, these combinations will form the basis of land unit concepts but will need to be organized and sampled at smaller mapping scales.

- If land units are being rated for current habitat suitability, then samples should be located to include sources of land disturbance. If, however, inherent land capability is being assessed, then land disturbance factors should be omitted.

- At smaller mapping scales, functionally similar map units should be aggregated to facilitate field sampling and subsequent analysis.

Preparation of data sheets

Data sheets are necessary for efficiently recording and organizing the survey data. Standardized sampling forms are not available for most areas or inventory techniques, mainly because of the large variability in detail, scope, and objectives between projects. One exception is the British Columbia Ministry of Environment which has produced a number of useful documents for standardizing approaches and definitions for ecological data collection (Luttmerding *et al.* 1990).

Consideration should be given to using hand-held computers for direct data input. This method can reduce transcription errors, reduce data input labour costs, and produce derived variable values.

Training/orientation of the wildlife field team

For larger inventories, which may require three or more biologists, it is useful for the crew leader(s) to conduct an orientation session to familiarize crew members with the field techniques and to standardize data collection procedures. Technical staff should be supplied with reference material to aid the identification of important plant species, aquatic forms, landforms, etc. The wildlife team members should also spend some time working with the rest of the ELC team both on air photo interpretation and in the field, to fully appreciate how the ELC is being conducted. This can be accomplished, in part, by including one of the ELC mappers at the orientation session.

Field data collection

Collection of wildlife habitat field data is essential to any ELC that intends to incorporate wildlife resource values. It may seem reasonable to argue that the relative importance of a map unit to a wildlife species could be inferred solely through subjective

expert analysis or computer modelling of the particular combination of habitat attributes occurring within it. There are a number of reasons why this is not advisable and in fact can lead to misleading interpretations of wildlife habitat importance:

- Wildlife use of habitat is a very complex and dynamic process, the details of which are currently poorly understood for most wildlife species.
- Wildlife use of habitats is often "ecoregion-specific." As such, generalizations or extrapolations from studies in one region are often not valid in another region.
- Modelling of wildlife habitat suitability or capability is a relatively new and evolving field that requires field data for model refinement and validation.
- In some cases, areas of land may be highly suitable to wildlife in terms of habitat availability, but local land disturbances may discourage wildlife from using the area. Fieldwork is often the only way to determine this.
- Existing land classifications often fail to include or quantify the particular land attributes required to accurately rate the importance of land units to the species of concern. Fieldwork is often necessary to fill these data gaps.

Wildlife managers and land use planners should recognize that wildlife field data collection is an integral component of an accurate and objective ELC and shortcutting on this aspect can seriously constrain the quality and range of wildlife evaluations that may be subsequently conducted.

Some of the principal functions of wildlife field data collection within an ELC context are:

- to attain an objective measure of relative levels of use of land attributes, including landforms, vegetation, surface water features, and combinations thereof;
- to establish benchmark population data for estimating the wildlife carrying capacity of individual and combined map units;
- to develop criteria for the evaluation of wildlife habitat suitability or capability on an ELC map unit basis;
- to provide an objective framework for verifying population density estimates generated by wildlife/habitat modelling procedures;
- to locate areas of "critical wildlife habitat" and significant concentrations of wildlife;
- to locate within map units the occurrence of "specific habitat elements"--i.e., features that are important or essential to a wildlife species but are not necessarily implied by the map unit concept (e.g., raptor nests, coyote dens, etc.); and
- to familiarize the survey biologist with the study area, as there is no substitute for "personal" experience with wildlife use of map units in terms of the quality of subsequent assessments and report production.

Budget limitations and study area size often prevent field data collection programs from achieving statistical confidence in results. However, the results of "less than statistically significant" field programs can still be effectively used in support of subjective or modelled assessments of land unit importance. Summarized field data, in conjunction with existing literature and in consultation with species experts, can be referred to in assigning relative variable weightings within a wildlife/habitat model (see Chapter 3).

Biologists should avoid relying solely on the results of wildlife use assessments for evaluating relative land unit importance

unless highly rigorous field sampling is conducted. Van Horne (1983) cautioned against blanket acceptance of wildlife use assessments (rigorous or otherwise) to evaluate habitat suitability because of the potential for high concentrations of subdominant animals in less than optimal habitat.

For some wildlife species, more than one survey method may be used to evaluate map unit importance. For example, ungulate use of habitat may be measured by pellet group counts, winter track counts, aerial surveys, forage availability/use surveys, and radiotelemetry monitoring. By using multiple techniques, the accuracy of population estimates and map unit ratings can be cross-checked.

A wide variety of established wildlife inventory methods may be used within the context of an ELS. The particular field data collection technique(s) employed will depend on a number of potential factors, including:

- the management indicator species or species groups to be inventoried;
- the types and detail of information required (e.g., relative habitat use vs. population estimates vs. diversity indices);
- scale of mapping;
- field logistics;
- funding levels;
- quantities of baseline wildlife data already available; and
- timing of wildlife field data collection relative to the rest of the ELC fieldwork.

Wildlife habitat inventory techniques can be geared towards collecting both habitat use and habitat availability (supply) data. Both approaches can yield useful data in support of land unit evaluations. Certain techniques may incorporate both approaches simultaneously. An example is an ungulate sampling program that counts pellet groups along a transect line while simultaneously recording the percent cover of preferred forage species at regular intervals (Beak Associates Consulting Ltd. 1987). Habitat availability measurements are especially useful for species whose habitat use relationships are not easily observed or measured (e.g., bears).

Table 2.7 lists a number of wildlife inventory techniques that may be applied within an ELS context. The Appendix provides a more detailed review of some of the commonly used field data collection procedures, with specific reference to their application to ELS. The existing overview by Cooperrider *et al.* (1986) formed the basis for much of the Appendix. Luttmerding *et al.* 1990 provided additional wildlife inventory methods.

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Table 2.7:
Wildlife inventory methods that may be used within the context of an ELS, by broad wildlife species group

Species group	Method	Information gained
Mammals		
Ungulates	• Pellet group counts	Relative abundance, density
	• Winter track counts	Relative abundance
	• Aerial surveys	Density, population structure, productivity
	• Roadside surveys	Density, population structure, productivity
	• Browse/forage use	Relative abundance, habitat availability
	• Biotelemetry	Relative habitat use, food preference
	• Forage survey	Habitat availability
Carnivores	• Winter track counts	Relative abundance
	• Scent stations	Relative abundance
	• Live trapping	Density
	• Biotelemetry	Habitat use, food preference
	• Den counts	Habitat use
	• Scat analysis	Food preference
Rodents, lagomorphs	• Pellet group counts	Relative abundance
	• Track counts	Relative abundance
	• Live trapping	Density
	• Snap trapping	Relative abundance, presence/absence
	• Beaver lodge/feedpile surveys	Relative abunance, density
	• Muskrat pushup surveys	Relative abundance
	• Burrow counts (ground squirrels)	Relative abundance
Bats	• Mist netting	Presence/absence, relative abundance
	• "Harp" trapping	Presence/absence
	• Random observations	Presence/absence
	• Echolocation detection	Presence/absence, relative abundance
Birds		
Songbirds	• Spot mapping (grids)	Density
	• Call/song transects	Relative abundance
	• Mark/recapture	Population structure, presence/absence
	• Nest monitoring	Productivity
	• Point count	Relative abundance
	• Variable-circular plots	Density, relative abundance
	• Habitat layering	Habitat availability
Raptors	• Road counts	Presence/absence, relative abundance
	• Aerial surveys	Density, relative abundance
	• Roost/colony counts	Density
	• Nesting surveys	Presence/absence, relative abundance
	• Calling surveys	Relative abundance
Marshbirds, shorebirds	• Spot mapping of territory	Density
	• Nest mapping using drag-rope/drag-chain	Density
	• Strip transects	Density
	• Encounter rate index	Relative abundance
Waterfowl	• Nest counts	Productivity
	• Brood counts	Productivity
	• Aerial surveys	Density, relative abundance
	• Ground surveys	Presence/absence
Upland game birds	• Dropping counts	Relative abundance
	• Strip transects (calls or observations)	Presence/absence, relative abundance
	• Roadside counts (calls or observations)	Presence/absence, trends in population
	• Complete census (observations)	Density
Reptiles and amphibians	• Systematic search (e.g., road riding, scouring known habitats)	Presence/absence, relative abundance
	• Trapping (e.g., funnel traps, pitfall traps)	Relative abundance, density
	• Dip nets/seines	Presence/absence, relative abundance
	• Electro shocking	Relative abundance, density
	• Telemetry	Habitat use

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3. Assessing land/wildlife relationships via the ecological land evaluation

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Wildlife and habitat evaluation

Introduction

Society views wildlife as an important natural resource having economic, social, and ecological values. Good wildlife management, to optimize these values, requires information concerning the distribution, abundance, and quality of wildlife populations and habitats through space and time. Assessments of these resources are ultimately part of an overall information management system designed to acquire and organize knowledge in a way that will facilitate, and give direction to, human action (see Chapter 4).

Wildlife and habitat evaluation is the process of assigning value to defined geographic areas based upon the occurrence (potential or actual) of particular wildlife populations. Such evaluations aim to determine socioeconomic and ecological values of the wildlife resource as a basis for management decisions. These decisions may be directly related to the resource, as in the case of establishing hunting regulations and recreational viewing opportunities, or they may indirectly influence the resource, as in the case of developing forest harvest plans or implementing agricultural expansion through wetland drainage. In either case, informed management decisions require evaluations that clearly identify the relative importance or absolute value of different areas to wildlife species of management concern. Management decisions may require information not only on how important an area is, but also why it has a certain level or type of importance. Knowledge of the causal factors that influence the value of an area to wildlife enables managers to mitigate potential development impacts and identify enhancement opportunities.

The evaluation process may focus directly upon measurements of particular wildlife populations to assess their distribution and abundance on a seasonal or year-round basis. These population measurements are usually based upon sampling procedures that involve direct or indirect (e.g., animal signs) observations of a portion of the population occurring within defined areas.

In contrast to direct monitoring of wildlife populations, many wildlife resource evaluations examine the condition or status of the habitat. *Habitat* is defined here as the physical and biological environment (including climate) that provides or detracts from the essentials of food, cover, and space that are needed by a population of animals for reproduction, maintenance, and growth. Wildlife resource evaluation therefore may involve the measurement and analysis of habitat components for the purpose of determining the *potential* (capability) of a given geographic area to support a particular wildlife population over time.

For many wildlife species, it is easier to measure and evaluate habitat and associated population potential than to attempt to accurately measure or estimate actual populations. Some reasons for this are as follows:

- Animal populations fluctuate substantially through time and space.
- Individuals of most populations are very hard to observe in the field and are rarely amenable to remote sensing survey techniques.

- Many other nonhabitat factors, such as competition and predation, influence populations, and these factors are very hard to measure and properly factor into population estimates.

Wildlife managers should seek an appropriate mix of population and habitat assessments to support their management decisions. Once wildlife habitat is classified, selective and timely population sampling surveys can be employed to establish or validate land unit ratings, monitor population status, and provide benchmark carrying capacities. Long-term monitoring of wildlife populations may be accomplished through a combination of habitat change assessment and periodic population surveys. Wildlife habitat classifications and evaluations provide a useful framework for stratifying the periodic population sample surveys, ensuring a more reliable and cost-effective population estimate. Figure 3.1 illustrates the advantages of a habitat-stratified population survey design.

Ecological land survey (ELS) is a useful tool for classifying and evaluating wildlife habitat as a basis for surveying and evaluating wildlife populations. ELS has recently been used as a framework for stratifying moose population surveys in Alberta (Smith *et al.* 1987).

Types of evaluation

There are several kinds of wildlife evaluation, each of which provides different information and, therefore, potentially different applications. The terminology used for these evaluations is not well standardized and often results in confusion between inventory specialists as well as between these specialists and resource managers (clients). The following characterizes common, broad categories of wildlife resource evaluation.

Population status assessments

- *Current population status*--This is an evaluation of actual or estimated population levels within defined geographic areas as determined by direct or indirect sampling of animal numbers. These counts may serve as a basis for estimating population levels in unknown

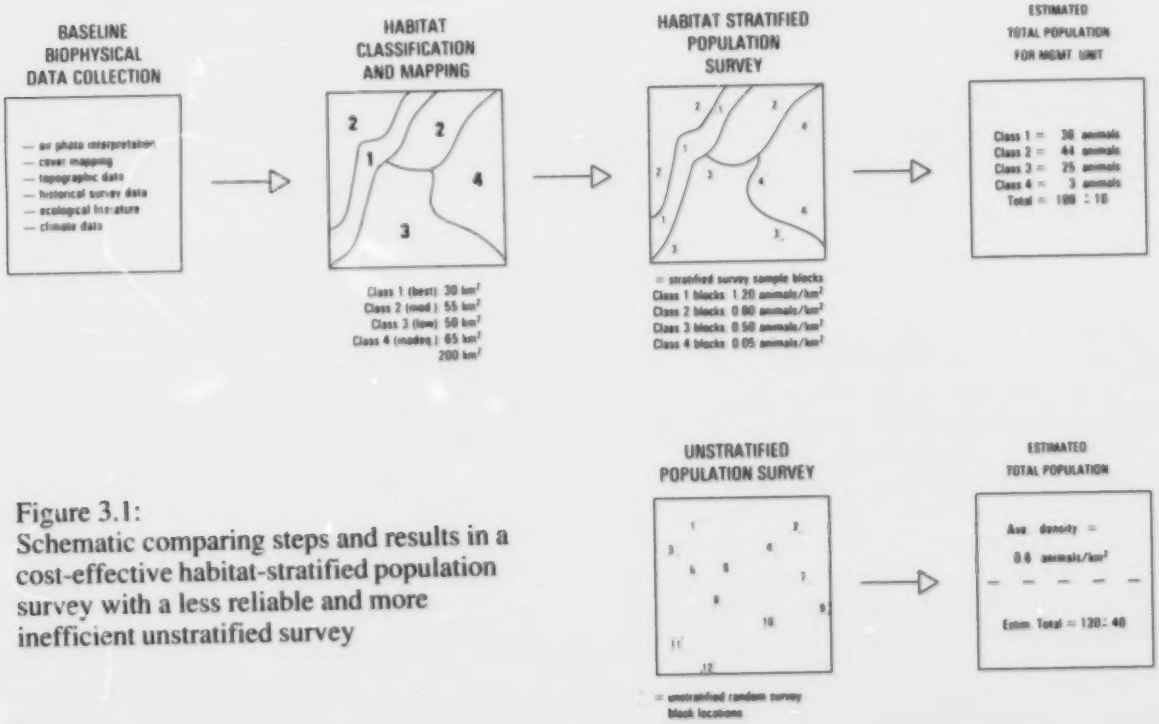

BASELINE BIOPHYSICAL DATA COLLECTION
HABITAT CLASSIFICATION AND MAPPING
HABITAT STRATIFIED POPULATION SURVEY
ESTIMATED TOTAL POPULATION FOR MGMT UNIT
UNSTRATIFIED POPULATION SURVEY
ESTIMATED TOTAL POPULATION

Figure 3.1:
Schematic comparing steps and results in a cost-effective habitat-stratified population survey with a less reliable and more inefficient unstratified survey

and unsampled areas. Considerable error and variation are usually associated with population estimates; and therefore, sampling procedures and confidence limits must be indicated. Many population surveys provide only a relative index of population abundance as opposed to absolute densities or total numbers. Such indices are designed only to compare populations from one place with another or from one time with another.

- *Critical or key area designations*--These designations identify localized areas that have been observed to support large concentrations of animals for certain periods of the year, or that provide essential life requisites needed for the maintenance of the population over its larger range. For example, these may be wintering areas, nesting or fawning habitats, migration corridors, or feeding concentration areas. The relative susceptibility of these areas and associated wildlife populations to human disturbance may be a factor in their designation as critical or key areas. Such designations may *appear* to be habitat assessments; however, they are frequently the result of population observations as opposed to habitat analysis. In fact, observations of high levels of localized animal use may reflect traditional behavioural factors more than any obvious habitat factors.

Habitat status assessments

Habitat assessments usually focus on easily measured physical and biological land attributes that contribute to, or detract from, the food, cover, and spatial requirements of a wildlife species. Other factors, such as land use (e.g., hunting pressure, cattle grazing intensity), competition, and predation levels, are usually not directly considered in these types of evaluations, even though such factors are often of indirect importance in assessing the availability of such habitat requirements as food and cover for security. These factors are very hard to measure and quantify.

Climate data may or may not be an integral component of a habitat evaluation. It is therefore important to clearly define the scope, time frame, and intent of habitat assessments. The following terms and definitions are suggested for three broad, generic types of habitat assessments:

- *Current habitat suitability*--This type of evaluation identifies the current ability of a land unit to provide a wildlife species with the environmental conditions needed for food, cover, and space. This assessment is current-time-specific and would reflect existing vegetation cover (including current successional stages) as influenced by natural and man-caused disturbance.

- *Inherent habitat capability*--This type of evaluation identifies the natural or inherent ability of a land unit to provide a wildlife species with the environmental conditions needed for food, cover, and space. This assumes little or no interference by man, with natural vegetation cover being present and representative of a relatively stable climax or disclimax type. The Canada Land Inventory (CLI) for ungulate capability and waterfowl capability represents this type of habitat assessment (Perret 1969).

- *Potential habitat capability*--This type of evaluation identifies the potential ability of a land unit at some future point in time to provide a wildlife species with the environmental conditions needed for food, cover, and space. This assessment is based upon a knowledge of the range of potential future environmental conditions that may occur in a given area as a result of predictable man-induced or natural vegetation successional changes.

The ungulate and waterfowl capability classifications conducted as part of the CLI would seem to best correlate with the above definition for inherent habitat capability. CLI placed considerable emphasis on physical

landscape characteristics and the "natural state" of the land, irrespective of present cover (Perret 1969). However, more specific reference to the actual application of CLI ungulate capability classification in British Columbia indicates that ratings are based upon the optimum natural vegetation stage (successional stage) that could be maintained with nonintensive management practices (Blower 1973). A major problem exists with the ambiguous terminology of "nonintensive management," which does not appear to have been clearly defined within the CLI context. More recent wildlife capability classification work in British Columbia, which evolved out of the CLI program, defines nonintensive management as including prescribed burning, grazing, logging, or protection (Demarchi *et al.* 1983). This latter perspective on capability classification would therefore more correctly fit within the above definition for "potential habitat capability." The point to be emphasized here is that a variety of potential habitat capabilities can occur for a particular species and land area. For example, it is conceivable that a high potential habitat capability could exist within an area for both woodland caribou and moose, but never at the same time because of the very different vegetation succession stages preferred by each species. Any assessment of this nature must clearly spell out the disturbance or management conditions and time frames for which such an assessment is being made. An environmental impact assessment does this when it tries to predict post-development habitat conditions (potential habitat capability) at different points in time, as compared with pre-development conditions (current habitat suitability). Inherent habitat capability may be considered as the relatively stable natural end point of many possible potential habitat capabilities that can exist within the natural vegetation chronosequence. Figure 3.2 illustrates the relationship of time

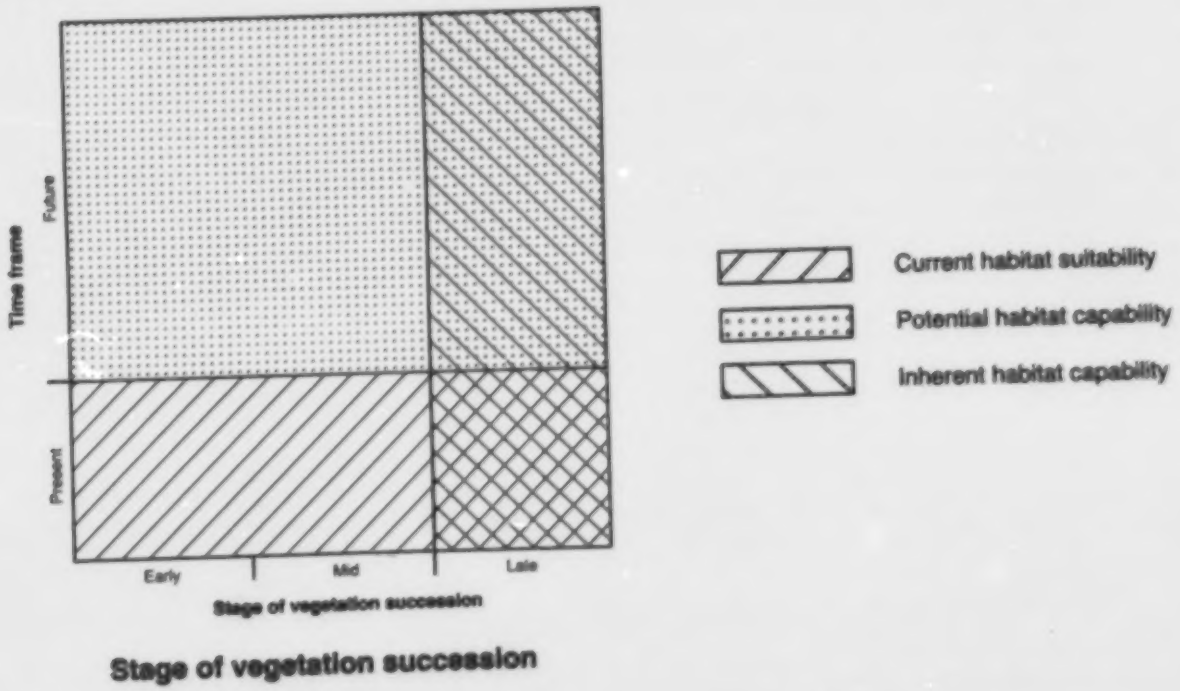


Figure 3.2:
Three generic types of habitat assessment as defined by time frames and stage of vegetation succession

frame and stage of vegetation succession to these three types of habitat assessment.

Population potential or carrying capacity is frequently estimated for the above-noted habitat assessments, as wildlife managers are ultimately concerned with how these habitat measurements and evaluations translate into numbers of animals. Table 3.1 presents an example of ungulate carrying capacities used in British Columbia that can help to define or qualify habitat assessment ratings.

Environmental impact assessment techniques, such as the U.S. Fish and Wildlife Service's (1980) Habitat Evaluation Procedures (HEP), frequently use a comparison of current habitat suitability (before development) with potential habitat capability (after development) to determine the impacts on wildlife habitats and populations from proposed development scenarios. In this case, habitat units (HUs) are calculated as a function of the geographic areas to be affected and a habitat suitability index (HSI) rating. Habitat units are an abstract relative measure but could be correlated with potential population densities given appropriate empirical observations.

Calculations of population potentials, or carrying capacities, using only habitat suitability assessments frequently do not provide realistic estimates of current population levels. Current populations are often below habitat carrying capacity for a variety of reasons, including land use disturbances, such as heavy hunting pressure, industrial developments, and transportation corridors, as well as periodically high predation levels or severe weather conditions.

Multiple species occurrence assessments

Increased concern with nongame wildlife species in recent years has resulted in assessments directed towards presence/absence ratings and species/habitat diversity measurements. The relationship between the life requisite needs for feeding and reproduction of a wildlife species and the vertical vegetation structure within a

Table 3.1:
Carrying capacity estimates for ungulate capability class ratings[1]

Classes[2]	Capability	Carrying capacity (animals/km^2/year)		
		Moose	Elk	White-tailed deer
1C	very high	7.6-9.0	16.4-19.5	26.4-31.5
1B	very high	6.1-7.5	13.1-16.3	21.1-26.3
1A	very high	4.6-6.0	9.9-13.0	15.9-21.0
2	high	3.1-4.5	6.6-9.8	10.7-15.8
3	moderate	1.6-3.0	3.4-6.5	5.4-10.6
4	low	0.4-1.5	0.8-3.3	1.2-5.3
5	very low	0.1-0.3	0.1-0.7	0.1-1.1
6	none	0	0	0

1 From Demarchi *et al.* (1983) for use with ecosite (1:50 000 scale) mapping.

2 Ranges calculated using the maximum of Class 1A as 100%. Classes 5 to 1C, respectively, are: ≤ 5%; 6-25%, 26-50%; 51-75%; 76-100%; 101-125%; 126-150%. The use of decimals is to prevent rounding errors; an estimation of carrying capacity to this accuracy is not expected.

particular cover type and climatic region can be used as a basis for determining the likely presence or absence of individual wildlife species or groups of wildlife species (guilds, life forms) that have overlapping habitat requirements (Thomas 1979; Short 1984). The management concern underlying many of these assessments is usually twofold:

- Endangered, threatened and vulnerable wildlife species must be maintained at, or increased beyond, existing population levels and distributions, and other species must not become endangered, threatened, or vulnerable.

- Wildlife species diversity is desirable and reflects a healthy and stable environment, as well as increasing recreational opportunities for the public.

These two perspectives can frequently be at cross purposes, and many endangered, threatened, and vulnerable species are associated with low diversity or very localized and unique communities of plants and animals.

Multiple-species assessments often involve the identification of ecological species groupings variously identified and defined as guilds (Sveringhaus 1981), life forms (Thomas 1979), or habitat dependency groups (Bonar *et al.* 1990). An indicator species is selected from each species grouping to represent the habitat requirements more or less shared by the other species in the group.

The guilding approach was used in a study in Alberta that looked at wetland drainage scenarios for increasing agricultural production and evaluated the potential impacts to wildlife. Green *et al.* (1986:3) felt that it was not feasible to examine the full range of individual species affected, as "...much of the material collected would potentially be redundant, as many species have similar habitat requirements." The study design therefore grouped species with strong similarities in their use of wetland zones (i.e., the water column [subsurface], open water zone [surface], emergent vegetation zone, shoreline zone, etc.) into wildlife guilds. A representative key species was selected for each wildlife guild (i.e., Mallard for dabbling waterfowl, Common Snipe for bog/fen shorebirds), and then a habitat assessment model was developed for each key species, focusing on its specific wetland habitat requirements. More recently, a similar process has been used to form habitat dependency groups and select indicator species for the purpose of conducting wildlife habitat supply analyses within the *Weldwood Hinton Forest Management Agreement Area* of west-central Alberta (Bonar *et al.* 1990). The result is that 30 indicator species are used to represent the habitat and population status of 284 terrestrial vertebrate species for the purpose of integrated timber and wildlife management--a much more practical and workable situation.

Some researchers question the validity of using indicator species as representative of other species when modelling land/wildlife relationships (Block *et al.* 1986; Chalk 1986). It seems difficult enough to adequately define and assess habitat suitability/capability for individual species within portions of their range, let alone for a group of ecologically similar species. The use of wildlife guilds and multiple species assessments is discussed in more detail by Cooperrider (1986), Short (1983), and Thomas (1979).

Wildlife diversity assessments can be used as an aid to identifying management indicator habitats, or habitat elements, that are of particular importance to a group of wildlife species of management concern (Harcombe 1984). The monitoring and protection of management indicator habitats can serve as a practical means of ensuring wildlife species diversity, or as an aid to the protection of threatened, endangered, and vulnerable species. In many cases, specific indicator habitats are more easily managed and monitored than indicator species or species guilds. Indicator habitats are not necessarily wildlife-species-specific but rather are

recognizable natural plant and animal communities. Vegetation associations are usually the main distinguishing features, similar to Daubenmire's (1968) "habitat types." These types can be assigned wildlife values depending upon geographic location. The recently launched Endangered Spaces program of the World Wildlife Fund - Canada (Hummel 1989) reflects this habitat focus as a means of addressing endangered species management concerns.

Review of wildlife resource assessment techniques during the past 10 to 15 years shows an increasing reliance upon habitat evaluations, as opposed to direct population measurements (Eccles and Stelfox 1985). This is particularly true for environmental impact assessments in which conditions before and after development need to be compared. Also, assessments for the purpose of making public declarations on resource status and trends, and for aiding wildlife management decisions and planning priorities, are frequently dependent upon habitat evaluation as an indirect measure of estimating population levels and trends. As previously mentioned, one of the reasons for this shifting emphasis is the difficulty and cost associated with obtaining good quality population data. Another reason is that more of the wildlife manager's attention is being directed at land management as an increasingly important, if not primary, means of managing wildlife populations. This is reflected in programs such as the Prairie Habitat Joint Venture of the North American Waterfowl Management Plan, and renewed efforts at integrated forest management. Both ecological land surveys and land/wildlife relationship models offer considerable potential in aiding the required evaluations of wildlife resources.

Land/wildlife relationship models

Introduction

Wildlife managers require evaluations of the wildlife resource that are explicit, quantifiable, and relevant to the decisions they must make. Bits and pieces of diverse data have to be collected and assimilated into useful packages of information that can facilitate resource management. Models can serve as tools to produce wildlife resource evaluations that are well documented, repeatable, and quantifiable. This need, and in some cases legal requirement, to quantify wildlife resource values has resulted in substantially increased efforts over the past several years to model land/wildlife relationships.

Webster's New Collegiate Dictionary (1975) defines a model as "a system of postulates, data, and inferences presented as a mathematical description of an entity or state of affairs." Gélinas (1988) describes a model as a simplified representation of reality that presents significant features or relationships in a generalized form.

Land/wildlife relationship models are specifically designed to assess and predict the value of land features (habitat) and land areas to the maintenance and productivity of identified wildlife species. Such models may be a simple written or verbal description of the habitat preferences of a wildlife species within a portion of its geographic range. However, to meet the needs of the modern wildlife manager, descriptive assessments should probably be translated into quantitative scoring systems that involve mathematical formulations of varying complexity.

A wildlife biologist creates a very simple model when developing scoring criteria or weighting factors for biological variables measured in the field and related in value to a particular wildlife species. A very simple habitat evaluation may involve mathematical summation of the scoring criteria and assignment of the scores to certain classes of habitat value. Because we are dealing with very complex biological phenomena, good models generally have to be more structured in terms of the connections or

interrelationships of habitat features as they contribute to the well being of a wildlife species.

Models are valuable because they make the intuitive or invisible assumptions of the wildlife biologist more visible and tangible. Models provide an environment in which to ask questions and to test assumptions. The process of model building results in the identification of deficiencies in data and our understanding of systems behaviour and animal ecology. Models are really nothing more than generalized hypotheses of reality. They can be invalidated but not necessarily proven true. Salwasser (1986) summarized the three roles of models in conservation as:

- explicit rules for making decisions;
- applied syntheses of the state of knowledge; and
- expressions of the linkages between causes and effects.

Subjective evaluations by a wildlife biologist, or group of biologists, have been commonly used for habitat assessment in the past. Such evaluations can provide very useful and realistic results. However, they do have the limitation of not being repeatable, of incorporating selective individual biases, and of not being available for scrutiny by others. A model really forces the biologist to define by written description and mathematical formulation ecological phenomena and the relationships of animal populations to their environment.

All habitat evaluation models rely on the assumption that *habitat factors*, such as vegetation, soils, and surface water features, influence an area's ability to supply a wildlife species with its *life requisites*, such as food and cover. Furthermore, it is assumed that the correlations between habitat factors and life requisites can be structured within a predictive model so as to establish quantifiable relationships needed to assess the relative or absolute value of an area to a wildlife species or group of species. Salwasser (1986) further suggested that most wildlife/habitat relationship models assume, or imply, that some aspect of populations can be predicted from some aspect of habitats.

The following discussion outlines some of the basic precepts, characteristics and difficulties associated with habitat evaluation models, as well as offering some guidelines for their development and application. Also discussed are the pros and cons of applying land/wildlife relationship models within the context of ELS.

Model objectives

The first step in the development of land/ wildlife relationship models is to clarify model objectives and desired outputs. The type of numerical scores or habitat class designators that are desired as end products should be identified at the outset. Also, the scope of the modelling process must be known in terms of the wildlife species to be considered and the geographic area to which the model is applicable. Models should be specific to those portions of a species range where habitat preferences are known to be similar. More than one model may have to be developed for a species that is widely distributed and occupies quite different regional environments (e.g., ecoregions) within its total range. Each model would define species/habitat relationships that are relatively constant within an ecoregion. Bailey (1976) defined an ecoregion as "a geographical area over which the environmental complex, produced by climate, topography, and soil, is sufficiently uniform to permit development of characteristic types of ecologic associations". The geographic applicability of a model must be clearly defined.

Model components

A second step in the development of land/ wildlife relationship models is the

assimilation of knowledge concerning a wildlife species' ecology and its habitat requirements and preferences relevant to the area under study. This usually involves a thorough review of the literature and unpublished fish and wildlife file data, as well as consultation with local species experts. Considerable care must be taken in utilizing research information collected from other geographic regions which may not be applicable to local and regional study area conditions. Also seasonal variation in habitat requirements should be identified.

Habitat requirements should be documented in the context of life requisites, such as cover, food, and space. Cover may be further broken down on the basis of thermal cover, escape or hiding cover and reproductive cover. These life requisites must be described in such a way that they can be associated with ecological factors that lend themselves to classification and measurement. Table 3.2 outlines the format of habitat requirement summaries developed for selected wildlife species in Alberta (Nietfeld *et al.* 1984). The summaries become part of the model documentation and provide supporting justification for the model design. Similar summaries form an integral part of the HEP models (U.S. Fish and Wildlife Service 1981).

As a result of this review of the habitat requirements of selected wildlife species, it is then possible to select a few habitat factors or *physical and biological variables* that are strongly correlated with the provision of food or cover and that can be measured in a cost effective manner. For example, the percent composition of conifer trees in the forest canopy may be a good measure of the degree of thermal cover available to moose in different forest cover types. Depending on the study, it may be necessary to select only variables that can be identified and measured through remote sensing.

Table 3.2:
Outline for habitat requirement summaries of selected wildlife species in Alberta*

- Cover
  - Vegetation
  - Landforms and topography
  - Aquatic forms
  - Climate
- Food
  - Vegetation
  - Landforms, topography, and soils
  - Aquatic forms
  - Climate
- Space
  - Home range
  - Population distribution and densities
- Spatial considerations
  - Size, shape, and juxtaposition of habitat components
  - Significance of disturbance phenomena
- Limiting factors
- Regional variations

* Adapted from Nietfeld *et al.* 1984.

An attempt should be made to select only a few variables that are considered to be the best indicators or predictors of life requisite habitat conditions. It may also be desirable to focus on only a particular season of the year that is considered most critical to the continued survival of the species within the study area.

The U.S. Fish and Wildlife Service (1981) recommended using the following criteria for identifying suitable model variables:

- the variable is related to the capacity of the habitat to support the species;
- there is at least a basic understanding of the relationship of the variable to habitat (e.g., what are the best and worst conditions for the variable, and how does the variable interact with other variables?); and
- the variable is practical to measure.

It may be helpful to use a tree diagram such as shown in Figure 3.3 to identify useful model variables. This approach separates habitat requirements into less complex components, each of which can be related to a set of measurable variables. The final selection of model variables should be justified by the habitat requirements previously documented. Salwasser (1986) suggested that the habitat variables must include those parameters that management decisions will affect if the model predictions are to be useful in assessing alternative management actions. In the case of models developed to assess wildlife habitat supply scenarios for different timber harvesting regimes in the Weldwood Hinton Forest Management Area, priority was placed on using forest inventory (tree stand) variables (Bonar *et al.* 1990).

Model structure and operation

The third step in developing models is the actual structuring of quantifiable relationships between the biophysical variables and other significant model components already identified so that an overall habitat suitability evaluation can be achieved. The development of a tree diagram as shown in Figure 3.3 begins this structuring process by showing which seasons of the year and which life requisites (e.g., food and cover) will be used as key indicators or measurements of habitat quality. Appropriate habitat factors or biophysical variables that can be used to assess a particular life requisite during a particular season of the year must then be selected. It must then be decided how numerical suitability measurements, ratings, or scores are to be calculated for each variable. This may involve the use of ranking procedures for a range of potential variable categories as in the case of the Alberta species/habitat relationship models (Table 3.3) or the use of habitat suitability index graphs as in the case of HEP models (Figure 3.4). Once determined for individual variables, the model must define the quantitative relationship between these variables so that a single overall habitat assessment value can be achieved. A variety of descriptive and mathematical approaches can be used. An excellent review of various approaches, including word models, mechanistic models, pattern recognition models, Bayesian probability models, and multivariate statistical methods, is provided in U.S. Fish and Wildlife Service (1981). Some of the important questions for consideration in defining the relationship between variables within a model include the following:

- Should some variables carry more weight or importance than others? An example of variable, life requisite, and seasonal habitat weightings is shown for the Alberta Fish and Wildlife Division model for moose (Figure 3.5).
- Should low scores for some variables be limiting to the overall habitat suitability or can they be compensated for by other variables? The use of limiting factor or compensating relationship considerations in a model must be based on a sound understanding of a wildlife species'

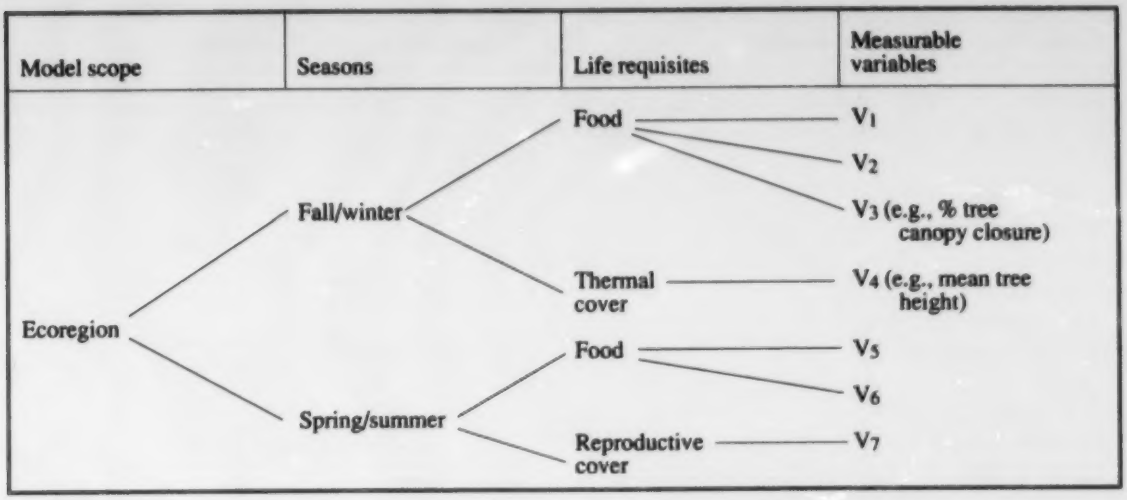


Figure 3.3:
Identification of model variables on the basis of seasonal life requisite needs for a particular wildlife species and ecoregion

Table 3.3:
Example variable ranking in species/habitat relationship model for moose in Alberta (modified from IEC Beak Consultants Ltd. 1984)

Species: moose; seasonal habitat: fall/winter; life requisite: food; variable: vegetation cover		
Variable ranking (value)	Variable category	Rationale
Best (3)	S (shrub) S/HM (shrub/mixed herb complex) FD (deciduous forest)	Categories that provide the greatest amounts of deciduous trees and shrubs for browse.
Moderate (2)	HM/S (mixed herb/shrub complex) FMD (mixedwood forest-deciduous dominant) PD (deciduous parkland) W (wetland) GD (deciduous groveland) FE (evergreen forest)	Shrubs are very important as a food source; therefore, HM/S is ranked moderate although the shrub coverage may be small. The other categories are ranked as moderate or poor because they have a progressively smaller deciduous tree and shrub component.
Poor (1)	FME (mixedwood forest-evergreen dominant)	Has a small deciduous tree and shrub component
Inadequate (0)	N (nonvegetated) AE (aquatic emergent) HM (mixed herb) C (cropland) CP (cultivated perennial range)	Nonvegetated sites offer no food. Moose are primarily browsers in the winter; therefore, categories without a woody vegetation component are ranked inadequate.

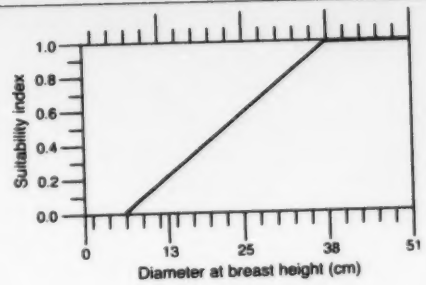
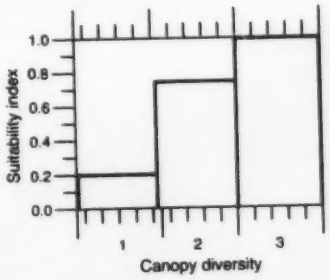
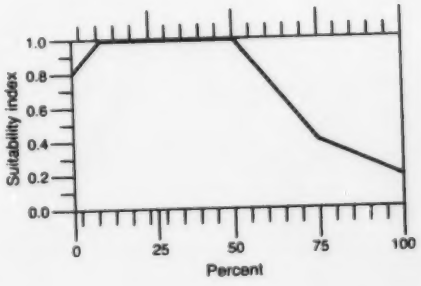
Cover type	Habitat variable	Suitability index (SI) graphs
EF, DF, EFW, DFW	V_2 Average diameter at breast height of overstory trees	
EF, DF, EFW, DFW	V_3 Tree canopy diversity 1. Single-storied stand 2. Two-storied stand 3. Multistoried stand	
EF, DF, EFW, DFW	V_4 Percentage of overstory canopy composed of deciduous species	

Figure 3.4:
Examples of habitat suitability index graphs for fisher (from Allen 1983)

ecology. These habitat component relationships must be structured into the model mechanics and mathematical calculations used.

Should the size and proximity of adjacent vegetation cover types or landscape units influence the habitat suitability rating? Wildlife species with relatively large home ranges are likely to find their food and cover needs, or their seasonal habitat needs, in quite different cover types or landscape types. This may require the use of juxtaposition or interspersion indices in the modelling process.

Cooperrider (1986) outlined four types of possible model calculations, shown below,

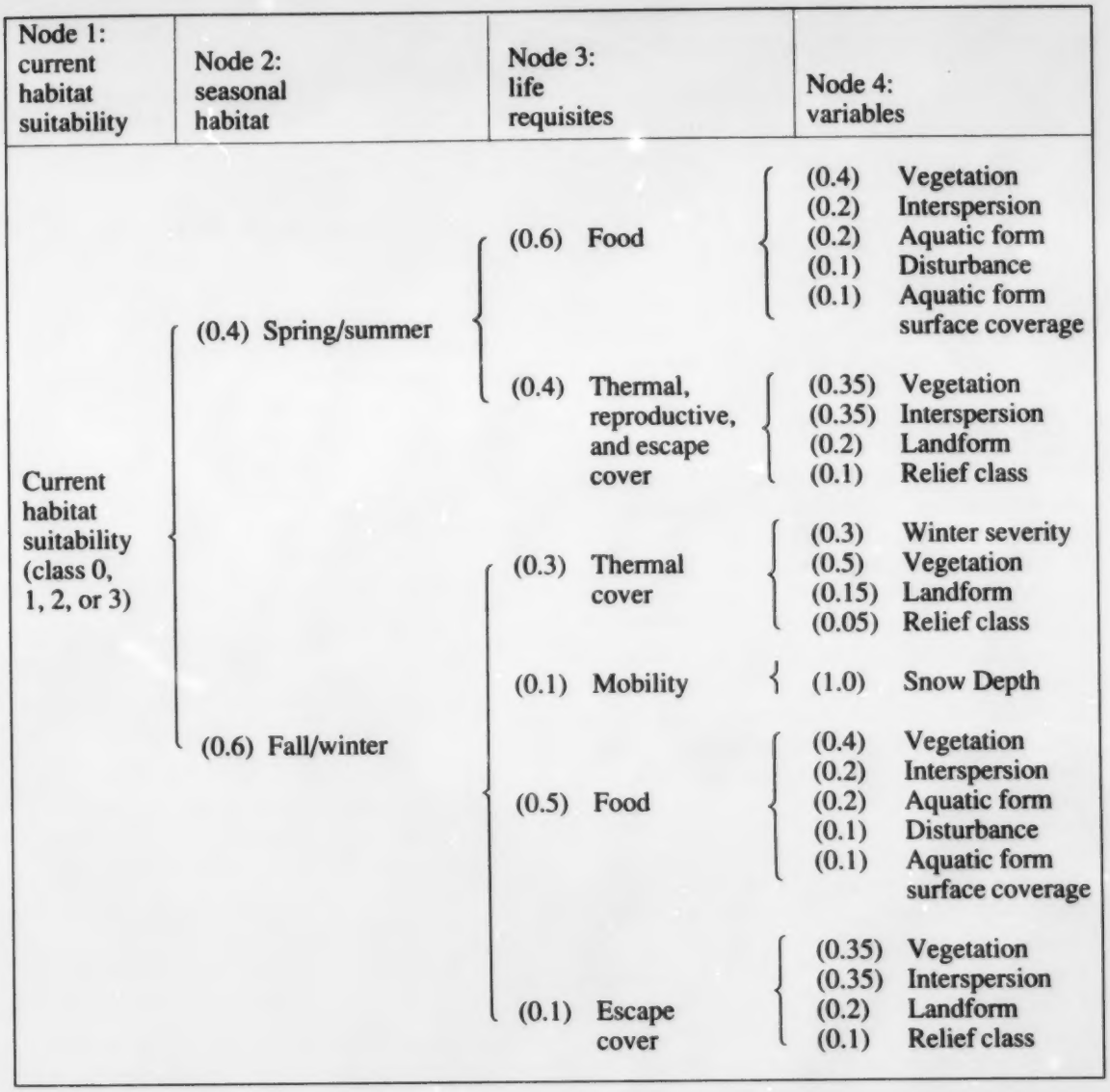


Figure 3.5:
Dendrogram used to identify the variables in the species/habitat relationship model for moose. Note: Aggregation weighting values are shown in parentheses. A current habitat suitability rating for a particular habitat subregion results from inputting the appropriate value (0-3) at node 4 from each variable ranking and then calculating weighted averages in a stepwise fashion from node 4 through to node 1 (from IEC Beak Consultants Ltd. 1984).

where each model calculates a habitat suitability index (HSI) from 0-1 for desert bighorn sheep based on the three habitat factors--a forage index (V1), an escape terrain index (V2), and a water availability index (V3). Suitability indices for each variable are also calculated within a range of 0-1.

- Simple additive model:
$$HSI = \frac{V_1 + V_2 + V_3}{3}$$

- Weighted additive model:
$$HSI = \frac{2V_1 + V_2 + V_3}{4}$$

- Multiplicative model:
$$HSI = (V_1 x V_2 x V_3)^{1/3}$$

- Limiting factor model:
$$HSI = \text{Min}(V_1, V_2, V_3)$$

Model documentation and validation

The fourth step in model preparation is the documentation on how the model has been constructed and how it operates. This should include identification of assumptions and rationale used, the scope and objectives of the model and the limitations of its applicability and accuracy. Thomas (1986) stated that "people who produce and use models have the responsibility to explain processes, assumptions, strengths, and weaknesses to those who make decisions based on those models."

Once developed, models are only working hypotheses of how certain components of the real world operate. Consequently, all models should be subjected to some form of validation and field testing. Such testing must reflect the original model assumptions and constraints. For example, a habitat suitability model is in most cases not designed as a population model. Therefore, it may not be appropriate to use population data to validate or invalidate the reliability of a habitat model. Blenden *et al.* (1986) point out that habitat models "do not contain birth- and death-rate components and make no pretext of being estimators of population densities at any single point in time." Van Horne (1983) discussed in some detail the problems associated with trying to use population data as an indicator of habitat quality. He suggested that reproductive success or mean body weights might be better indicators of habitat quality than population densities. A further problem in using population data to certify habitat quality is that the population counts are frequently of low reliability in the first place.

Schamberger and O'Neil (1986) argued that model tests are appropriate only for determining how well a model meets its stated objectives. If model assumptions and objectives are not clearly stated, tests will be nearly impossible to design and results will be inconclusive. They identified four levels of assumptions at which model testing could occur:

Level A: the relevance of indicator variables--e.g., that foliage density is positively correlated to insect densities.

Level B: the significance or appropriateness of a particular variable in the model--e.g., that insect densities are a significant and potentially limiting food source to the species under study.

Level C: the relative importance and interaction of model components--e.g., that if food supplies fall below a certain level they will have an absolute limiting effect on the species and will not be compensated for by other life requisites such as cover.

Level D: model output--e.g., that an HSI value is twice as high in one area as in another.

To test models at any of the above levels, it may be necessary to manipulate model variables under controlled conditions over time or between locations at the same time. Evaluation of predictive models, such as the HSI models of the U.S. Fish and Wildlife Service, may require monitoring in an operational setting over long periods of time so as to compare model predictions with observed conditions after project development.

Less sophisticated approaches to model validation may involve a comparison of model scores with a subjective assessment by an individual or group of experts. Such an approach was used to test HSI models in Alaska (Mulé 1982) and species/habitat relationship models in Alberta (Beak Associates Consulting Ltd. 1987). Both studies seriously questioned the validity of results from some mechanistic models. One of the advantages of relatively simple models, containing only a few variables, is that they will be easier to test as there are fewer assumptions built into them.

Summary

Land/wildlife relationship models can be valuable tools for analyzing data and generating information relevant to the larger process of wildlife management and land use planning. Salwasser (1986) suggests that models should ideally:

- be easy to understand and communicate;
- represent the major elements of control;
- run on commonly collected inventory data;
- provide information in terms of the outputs of concern; and
- be reliable in proportion to risks and values involved in the decisions.

Habitat modelling is still in its relative infancy. However, models that can provide well documented and explicit wildlife habitat assessments play an essential role in contributing information needed in the larger resource management process. They also play an important role in clarifying the limits of our current understanding of complex biological phenomena.

Ecological land survey as a tool for assessing wildlife and habitat values

Ecological land survey can be a very effective way of collecting, synthesizing and evaluating biophysical data needed to assess wildlife habitat status. The survey also provides mapped land units that can be used to efficiently stratify population surveys.

The basic assumption underlying the usefulness of ELS for evaluating wildlife resources is that wildlife populations select for specific attributes of their total environment in a reasonably predictable and meaningful manner at different stages of their seasonal and reproductive cycles. This assumption is supported by both ecological theory (see Chapter 6) and field studies of wildlife habitat use (e.g., Rongstad and Tester 1969; Hjelford 1973; Peek *et al.* 1976; Tilton and Willard 1981). It follows that specific environmental parameters, as classified and mapped into distinct units by the ecological land classification (ELC) process, may have either enhancing or limiting influences on wildlife populations.

It is impractical to collect reliable, quantitative population data for many wildlife species, particularly on an extensive basis, as is frequently required in Canada. Various techniques, including land/wildlife relationship models, can be used to establish semiquantitative relationships between ecological land units and wildlife productivity and population status.

As many wildlife management issues are tied to land use practices, the ELS approach strengthens the ability of wildlife managers to provide meaningful input to land use decisions. Also, other land management disciplines are better able to understand the nature of wildlife resource values.

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4. Supporting wildlife and habitat management

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Integrating with information and decision-making systems

Any type of resource inventory and assessment project must ultimately be part of an overall information management system designed to acquire and organize knowledge in a way that will facilitate and direct human actions. Inventory must be structured on the premise that it will form an essential platform from which reasoned action is pursued. An inventory program is most likely to be successful if it has a clear relationship to the organization's functions. The concept of baseline data underlying informed resource management decisions and actions is illustrated in Figure 4.1.

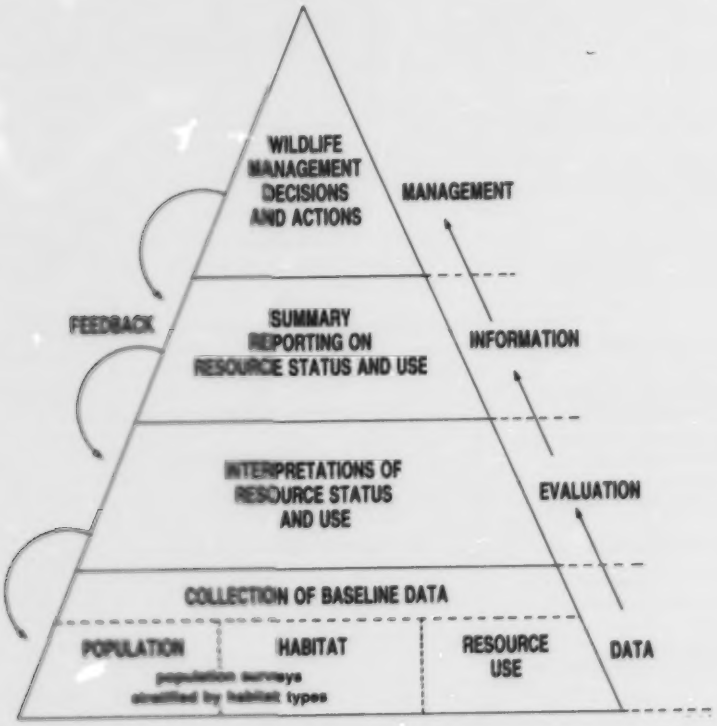

Figure 4.1:
A wildlife resource management information and decision-making system, illustrating the structured collection of large volumes of baseline data and conversion of them into smaller volumes of useful information tailored to highly focused management decision-making

Baseline data must be collected, interpreted and converted into useful information that addresses specific management concerns. If you do not know, in some detail, what the management concerns and questions are, there is a high probability that inventory data collected will not be the right data or the best and most useful data. Once collected, data flow through appropriate interpretations to the top of the pyramid. However, the design for baseline data collection and evaluation must be based on feedback and direction received from the top of the pyramid. Without that link, most inventories are doomed to irrelevance and obsolescence. Figure 4.2 provides more specific examples of the elements that may be included in baseline data, resource interpretations and summary reports, as well as target decisions and actions.

The development of information system models is very helpful in establishing the broader linkages between data collection or capture and a desired end point. Computer technology and the automation of data handling have helped to force a clearer understanding of these relationships.

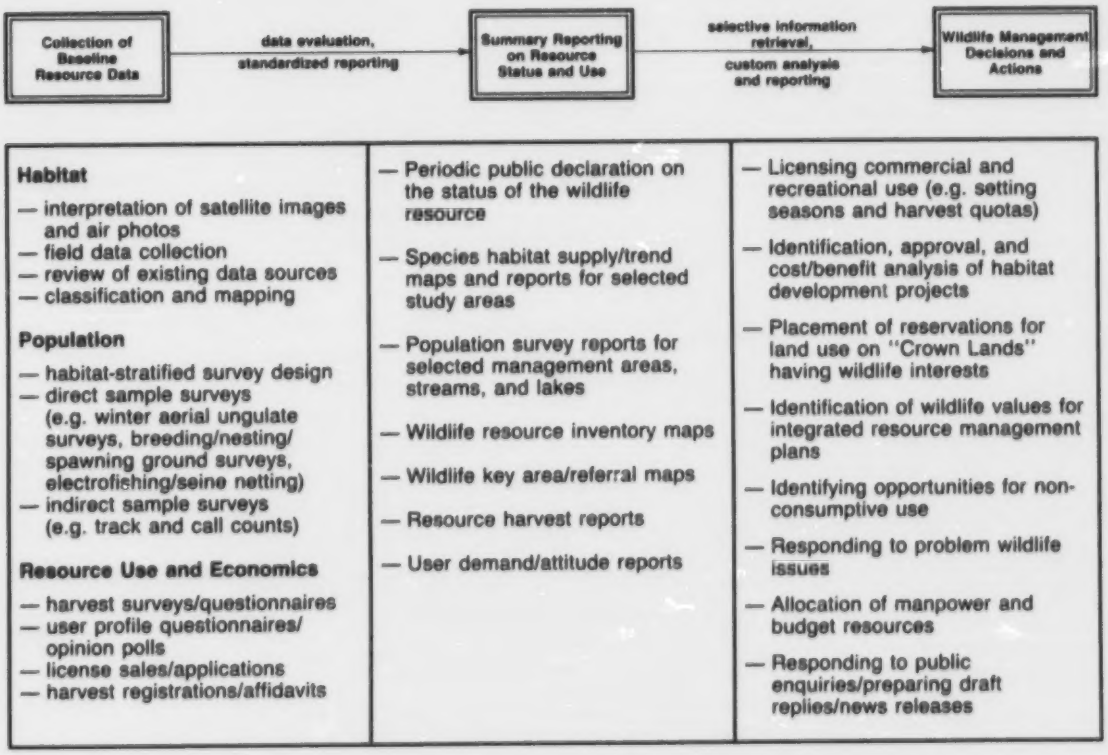
Collection of Baseline Resource Data
data evaluation, standardized reporting
Summary Reporting on Resource Status and Use
selective information retrieval, custom analysis and reporting
Wildlife Management Decisions and Actions
Habitat
— interpretation of satellite images and air photos
— field data collection
— review of existing data sources
— classification and mapping
Population
— habitat-stratified survey design
— direct sample surveys (e.g. winter aerial ungulate surveys, breeding/nesting/ spawning ground surveys, electrofishing/seine netting)
— indirect sample surveys (e.g. track and call counts)
Resource Use and Economics
— harvest surveys/questionnaires
— user profile questionnaires/ opinion polls
— license sales/applications
— harvest registrations/affidavits
— Periodic public declaration on the status of the wildlife resource
— Species habitat supply/trend maps and reports for selected study areas
— Population survey reports for selected management areas, streams, and lakes
— Wildlife resource inventory maps
— Wildlife key area/referral maps
— Resource harvest reports
— User demand/attitude reports
— Licensing commercial and recreational use (e.g. setting seasons and harvest quotas)
— Identification, approval, and cost/benefit analysis of habitat development projects
— Placement of reservations for land use on "Crown Lands" having wildlife interests
— Identification of wildlife values for integrated resource management plans
— Identifying opportunities for non-consumptive use
— Responding to problem wildlife issues
— Allocation of manpower and budget resources
— Responding to public enquiries/preparing draft replies/news releases

Figure 4.2:
Resource data and information as components of the wildlife management process (Adapted from Alberta Forestry, Lands and Wildlife and Energy 1987)

In Alberta, a Recreation and Conservation Resources Information System was developed to help identify lands that have a high suitability for various forms of recreational development and use. The initial conceptual model for the information system is shown in Figure 4.3. Necessary data inputs are shown on the left side of the figure, and desired information outputs for decision making are shown on the right side. The middle portions of the figure show three levels of interpretation and information synthesis that are required to get from the raw data to the desired end products.

Another example of a higher-level information system is a comprehensive data model that was developed for the primary business functions of the Alberta Fish and Wildlife Division. This data model is known as the Resource Evaluation and Licencing Management System (REALMS). It is composed of three main subsystems: Resource Management, Usage, and Ad Hoc Reporting, as shown in Figure 4.4. Each

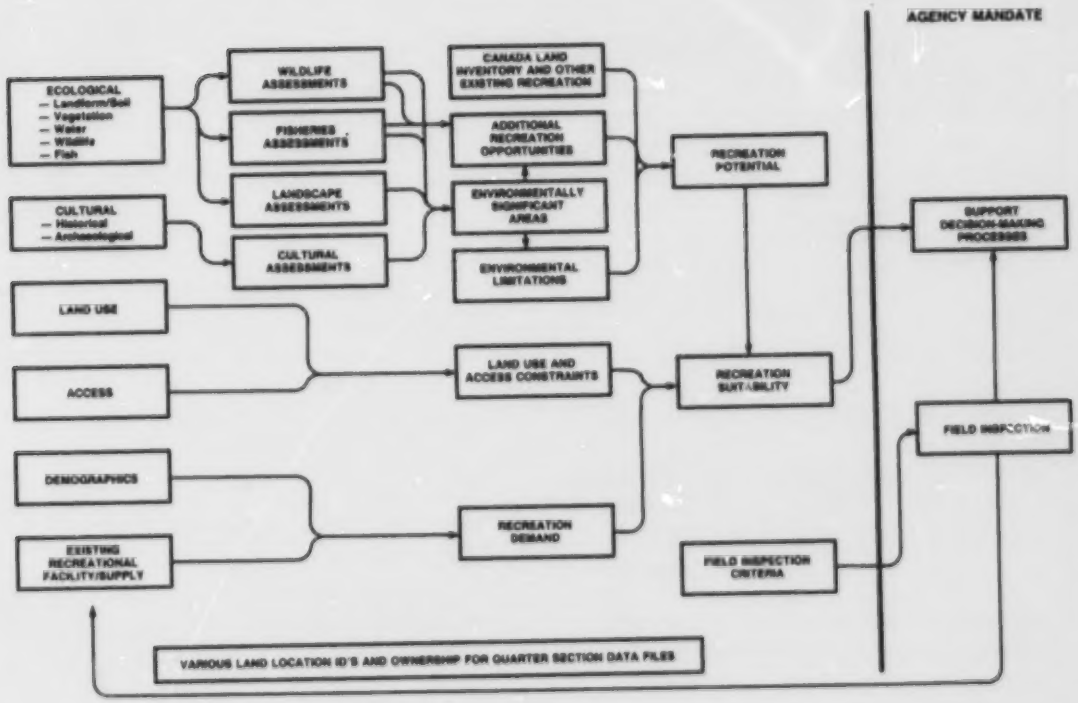

Figure 4.3:
Recreation and Conservation Resources Information System (adapted from Alberta Forestry, Lands and Wildlife 1986)

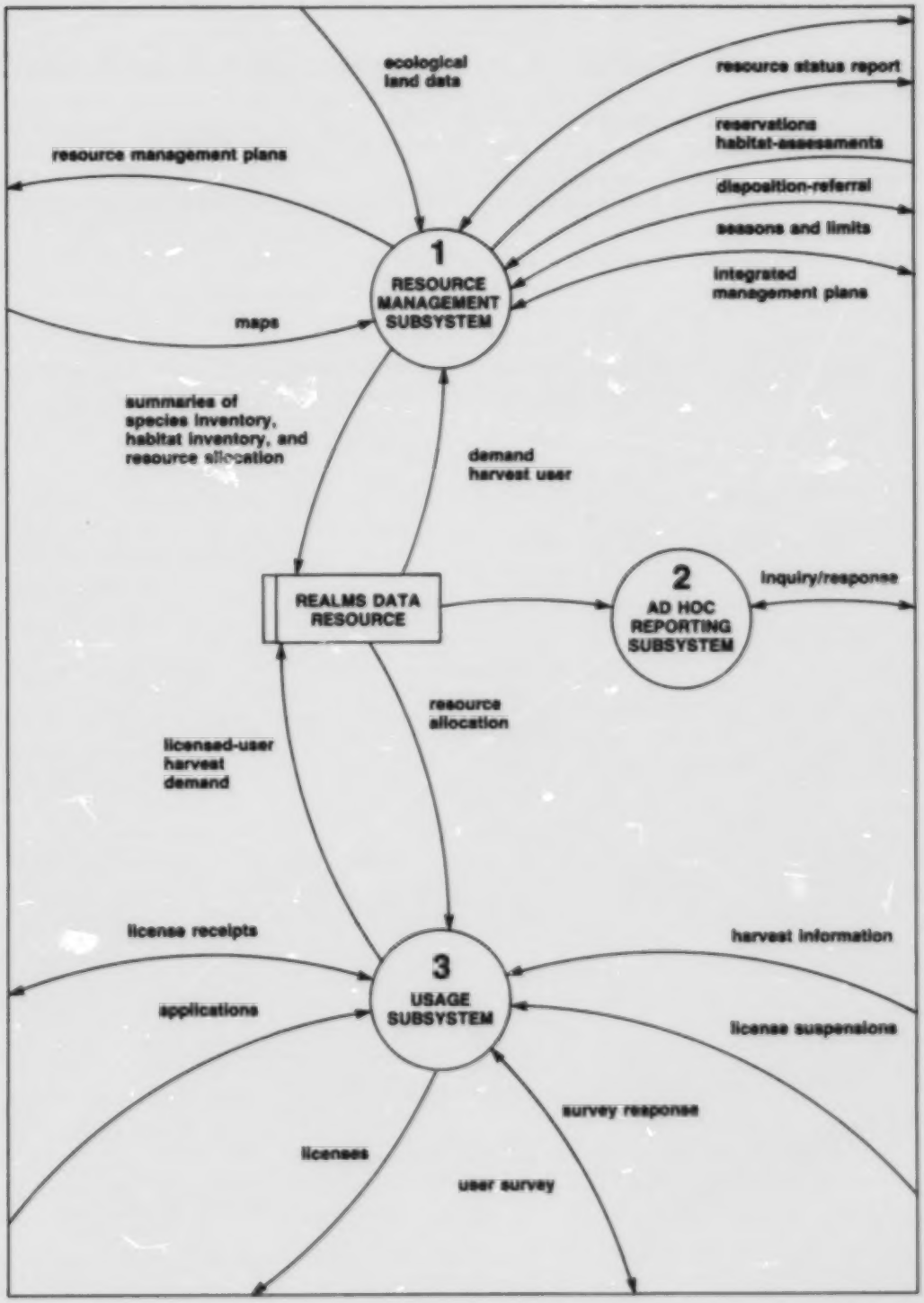

Figure 4.4:
Resource Evaluation and Licensing Management System (REALMS)--functional overview (adapted from Alberta Energy and Natural Resources 1985)

subsystem was broken down into more definitive data inputs and information outputs, as shown in Figure 4.5 for the Resource Management Subsystem. Such data models are essential for designing information systems, even if only portions of the system end up being automated.

Information systems can be as simple or as complex as necessary. The essential ingredients are that they clearly show the resource management and decision-making environment and how resource inventory and assessment activities are structured to impact on this environment. It is important to design ecological land surveys and wildlife resource assessments to properly integrate with broader decision-making activities. Ideally, resource managers, at appropriate levels in the decision-making process, formally approve major inventory and evaluation projects at an early stage in their implementation to ensure relevancy and managerial support.

Providing for client information needs

Introduction

No inventory or monitoring project is complete until the results are communicated through the appropriate decision-making forum (Zimmerman 1986). The ultimate success of any such project is essentially a function of its usefulness to the client.

Information delivery is often the most neglected aspect of an inventory and is likely the reason why so many products now gather dust on the shelves of their clients. A product may be an excellent piece of work, and it may even be state of the art, but if it is not well organized and attractively packaged, a client may not appreciate its full value and may not use it to the fullest extent possible. The way in which information is presented is critical to the acceptability of it and to the overall influence that it has on decision making. Modern wildlife and habitat managers function in a decision-oriented environment where the stakes are high and where the wrong decision could result in significant degradation of habitats and loss of wildlife. Therefore, not only must wildlife and habitat managers bring forward the information and data required to make the decision, they must bring it forward in a manner that is readily useable and has the potential to meaningfully impact on the decision-making process.

The importance of project delivery is demonstrated in the following case history, reviewed by Watson and Nimmo (1985). In 1973-74, a company conducted an aerial photogrammetric survey of agriculture in five Ethiopian provinces that were plagued by famine. The survey concluded that the crisis in the highland rain-fed crop production system was likely to be persistent and recurring. The company recommended a two-pronged strategy to avoid the next famine: radical agrarian reform, and a monitoring program based on satellite imagery to provide information with which to operate a grain purchase, storage, and redistribution system to eliminate oscillating grain production rates. Unfortunately, these and many other recommendations were not effectively carried out, for the following reasons:

- The report was written in English, which is not the primary or secondary language of most Ethiopian government officials.
- The report was overly long, containing 239 pages of information, with numerous densely structured tables and closely argued paragraphs.
- The report did not facilitate discussion and debate, which significantly reduced its impact on people living in a culture with traditionally oral communications systems.
- Information in the report was outdated by the time that it was presented to the clients.

From another perspective, Jenkins (1983) stated that most attempts to deal with the

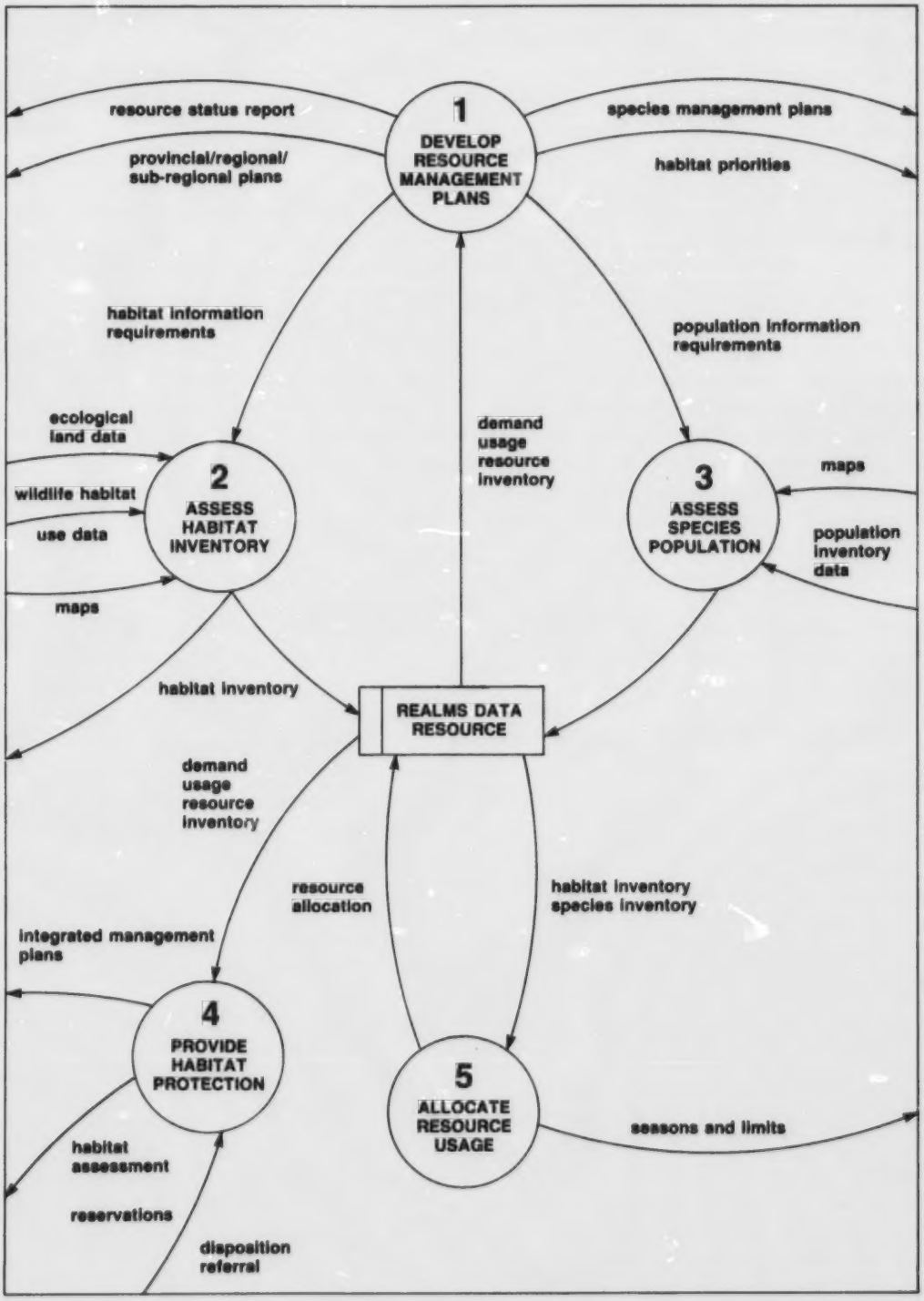

Figure 4.5:
Resource Evaluation and Licensing Management System (REALMS)- -Resource Management Subsystem (adapted from Alberta Energy and Natural Resources 1985)

collection, flow, and use of information have been unsuccessful for several reasons:

- The inventory was of short duration, quickly completed, and set aside.
- The inventory suffered from confusing and imprecise goals and objectives.
- The geographic scope was not appropriate (e.g., too broad).
- Too much money was spent amassing indeterminate amounts of information, while failing to collect information on and between sites that can be effectively compared and used to make management decisions.
- The methods of data collection were *ad hoc*.

To avoid these and other problems, a number of questions should be posed prior to developing a proposal or embarking upon a project. Each project can be characterized by a definitive set of unique questions relating to client needs, project planning, project implementation, and product format. The answers to these questions will assist in the design and implementation of a program which meets client needs.

Client groups

Identifying client needs is essential to the successful application of a product. In many cases the client will be required to pass the report on to other interested parties. Therefore, it should be determined who will use the report and in what context. Through consultation with the client, the needs should be interpreted in the context of the technical aspects of the project; these can be reinterpreted back to the client to ensure that everyone involved has a common understanding of the project. It is frequently desirable to go through a workshop consultative process to ensure that all parties agree on the project purpose, timeframes, and final reporting deliverables. Many professionals can describe cases where, in the absence of an ongoing review and approval process, the final project deliverables were quite different from those anticipated by the client.

In assessing a client's needs, the following details should be clarified:

- how much time the client will have to interpret and study the product;
- the client' information needs with respect to the study area;
- requirements regarding access to the logic, methods, and data sources;
- appropriate product format; and
- who, in addition to the client will use the product(s).

Planning the project

"The success of managing information can be measured by how efficiently a particular strategy meets the *requirements* of the user, evaluated in terms of attributes of the information and its flow" (Nichols 1985). In addition to getting to know and understand a client, it is critical to ask and answer a number of pertinent questions prior to designing the project to ensure that the methods will generate the appropriate data and results required to complete the final report. Once again, it is important to work closely with the client during this phase of the project to ensure that both parties agree.

Good project design can result in the development of a useful decision-making tool; poor project design can result in a failed project, which may negatively impact on the resource. Jones (1986) recommended that projects be designed using a problem identification or scoping process, which includes consideration of the following:

- Identify the issues.
- Reduce general problems to specific ones.
- Predict and analyze the extent of potential problems.
- Identify specific study objectives.
- Prioritize study objectives.
- Determine the types and levels of data required.
- Identify data collection procedures.
- Determine how to analyze, interpret, evaluate, present, and store the data.

Detailed discussions on project design techniques, data collection, and data analysis are found in chapters 2 and 3.

Product format

Most clients will be resource managers interested in information, not data. Detailed statistical analyses and complicated tables and figures should not be employed to convey information to managers (Jones 1986). The data may enhance the agency's data base, but the most useful aspect of the work is the information that gives the manager the power to make informed decisions and recommendations. Information can be presented in a number of ways, including text, maps and other graphic illustrations, tables (e.g., wildlife legend), and photographs. Products from previous projects can be examined to help clarify the desired presentation content and format. The most appropriate format for the project must be determined prior to the implementation, or during the early stages, of the project in consultation with the client.

It is important for the client to be able to distinguish between a technical baseline inventory product and a derivative summary product. The inventory product will be written in technical language suited to specialists, whereas the derivative products will contain a less technical, condensed version suited to support decision making. Most clients want both to enhance their baseline data and to carry forward a popularized or "user-friendly" document that can be reviewed by colleagues, managers, politicians, and the general public.

In an ELS context, most clients will be much more interested in the evaluation step than in the classification step. In this context, the interpreted habitat map is the basic decision-making tool. The following points may assist in the delivery of the information:

- The information should be a simple, clear, and concise distillation (evaluation) of large quantities of technical and detailed survey data.
- The resource evaluations and associated classes being used should be clearly defined. For example, when using the concept of current habitat suitability, the user must clearly understand the sense of the term, the differences in the classes, and whether class differences are relative or absolute (e.g., see Chapter 3).
- Evaluation products should, where practical, visually present results (e.g., maps and graphs).
- Map categories or class should be adequately defined, and excessive detail and clutter in map lines, coding symbols, and legend layout should be avoided--you can easily lose sight of the forest (information) if you are seeing too many trees (data).
- The most important results should receive visual prominence. Colour or pattern can add visual impact to maps, figures, or tables.
- Results should be presented in a language that the client can readily understand. Extensive use of codes and symbols

should be avoided, as these require excessive time and effort to interpret.

A standard reporting format for multiple products, or a series of products, should be used throughout the life of the project. This is especially important for large and widely used inventory/information products. Users develop a familiarity and comfort level with those products over time.

Project documentation

Summary information products must be supported by carefully documented technical data and information. This may need to be referred to for resolving decision-making problems. Dietz (1986) recommends that the following types of information be documented:

- Literature
- Abstract
- Project purpose
- Project design
- Study area description
- Methods
  - analysis
  - date of analysis
  - data sources
  - fieldwork/methods description
  - mapping methods (e.g., computer software used)
  - minimum map unit (e.g., pixel)
  - mapping categories and how they were identified
- Description of mapping categories
  - photographs
  - reliability of assessment
  - quantitative accuracy if possible
  - location of products
  - location of field data and photographs
  - glossary
- Digital Products
  - size of image
  - projection (origin)
  - raster/vector/quadtree organization
  - spectral class plot
  - class numbers with labels
  - archive tape
  - data format
- Map products
  - scale
  - legend symbols and classes

Improving resource information access

Efficient and effective use of information is critical to all kinds of decision-making. Improved computer technologies have become an invaluable tool for achieving this. Chapter 5 provides an overview of automated data and information technologies for wildlife and habitat management.

Summary

It is crucial that data and information requirements be determined during the initial phases of a project. This establishes the client's needs, the budget, the logistics, the data collection and analysis techniques, and the final product(s). The specific procedures and results for the duration of the project must be reviewed and verified with the client.

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Part B:

Support technology and theory

5. Automated data and information management

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Introduction

Resource managers work in a fast-paced, often chaotic environment where rapid and efficient access to data and information is mandatory. The manager is required to work to tight deadlines, with minimal funding, and large, often disparate sets of data, most of which have been collected by others. Contemporary management and research techniques no longer consist primarily of rubber boots, a spotting scope, a note pad, and a disposition toward working in difficult and often hostile conditions. Coping with this new, dynamic working environment, and getting optimum value for time and money, requires radical changes to the way in which business is conducted. For example, a number of tools and products are now available to aid in efforts to account for wildlife resources within complex, inter-disciplinary resource management programs. These include: portable electronic data collectors, radio-telemetry technology, computers, high-level aerial photography, Landsat and other satellite imagery and digital data, thematic maps, published literature and technical reports, and the results of field studies.

Computers are primary tools which can be employed to bring the data and information together efficiently and in a form which can be used to generate meaningful answers to the questions at hand. They are extremely powerful and can extend human intelligence to optimize the usefulness of the results of a project, by facilitating the processing of large data sets, allowing the manager to complete complex comparisons and calculations, and providing options for analyzing data within a space-time continuum (Peterson and Matney 1986). Computers have traditionally been used to store and analyze data and information for resource planning, modelling wildlife species-habitat relationships, modelling forest ecosystem dynamics, and monitoring plant and animal population dynamics (Marcot *et al.* 1988). Prior to the development and distribution of the microcomputer, early modelling and statistical analysis programs were developed for mainframe and minicomputers and were not readily available to resource managers, particularly those working in remote locations or within the limits of small budgets. Throughout the 1980s, however, the significant advances in the sophistication and capacity, and decreasing costs of microcomputers provided resource managers with a powerful new tool (e.g., Anderson *et al.* 1980).

Although this chapter does not address comprehensively the use of the computer in wildlife management, it does describe some of the technology and associated options available and brings its use into perspective within a natural resource management framework. Because computer modelling is an important aspect of many resource management studies, a brief description of the types of models is included.

Models

Models are structured, repeatable, and selective approximations of the real world

(Chorley and Haggett 1967), which are developed and employed to gather, synthesize, and analyze data and information (Kessel 1979). They help to assess the state of the environment, predict and compare the results of management actions (including no action), and provide methods of testing goals and strategies (Kessel 1979). Models are especially useful when dealing with complex multiple resource management issues. The three basic types of models -- descriptive, predictive, and decisive -- are discussed below.

Descriptive models characterize various aspects of the real world. They include maps, scale models, and descriptive equations (Morgan 1967, Walters 1971), and usually represent a synthesis of data and information. Historically, descriptive models have been emphasized most, whereby parameters are identified which humans perceive to be the most representative of the real world (Gélinas 1986, 1988). Modelling wildlife has been particularly difficult because each animal species (and in many cases each animal of the species) perceives the world in a unique and complex manner, often poorly understood by wildlife managers. We then attempt to translate our interpretation of an animal's perceptions into defined parameters, which we may organize into some form of structured framework, such as a classification system.

Predictive models are based on attempts to delineate and describe what might be expected to occur under a given set of conditions (Gélinas 1986, 1988), and they usually require data created in a descriptive model framework. Computer simulation models, for example, are frequently used for dealing with complex questions about human-caused impacts on the environment. Mosher *et al.* (1986) identified the following six criteria for ideal predictive models. They should:

1. accurately predict (80% of the time) the result of the action or condition;
2. be easy to parameterize;
3. contain variables which can be measured and understood;
4. contain parameters which are compatible with existing research and management programs;
5. contain parameters or variables which are important in the description of the resource; and
6. be applicable over all or most of the species range or adaptable to meet the objectives of species management decisions throughout its range.

Example predictive models are those of Smith *et al.* (1981) in which **FORLOB**, a loblolly pine simulation model, and **FORHAB**, a deciduous forest succession model, were used to predict available bird habitat.

Decisive models identify specific options respecting a preferred course of action or response under a specific set of conditions (Jeffers 1972, 1973). They depend upon the data and information derived from descriptive and/or predictive models. Formal description and application of decisive models, in part, have resulted from significant advances in the field of artificial intelligence (Expert Systems), which is reviewed later. An example of a decisive model is the Expert System of McNay *et al.* (1987) for identifying key winter habitats of black-tailed deer in British Columbia.

These three types of models are not necessarily mutually exclusive, and modern modelling procedures often contain aspects of all three (Fig. 5.1). As a simple example, consider a 1:250 000 topographic map which outlines elevational contours and provides additional information on slope. This is a descriptive model of the topography of the ground. A resource manager may examine the map to determine the best method of gaining access to a study site. The 100m contours are close together and the slopes are steep; given the steep terrain, it may be predicted that the study site cannot be reached

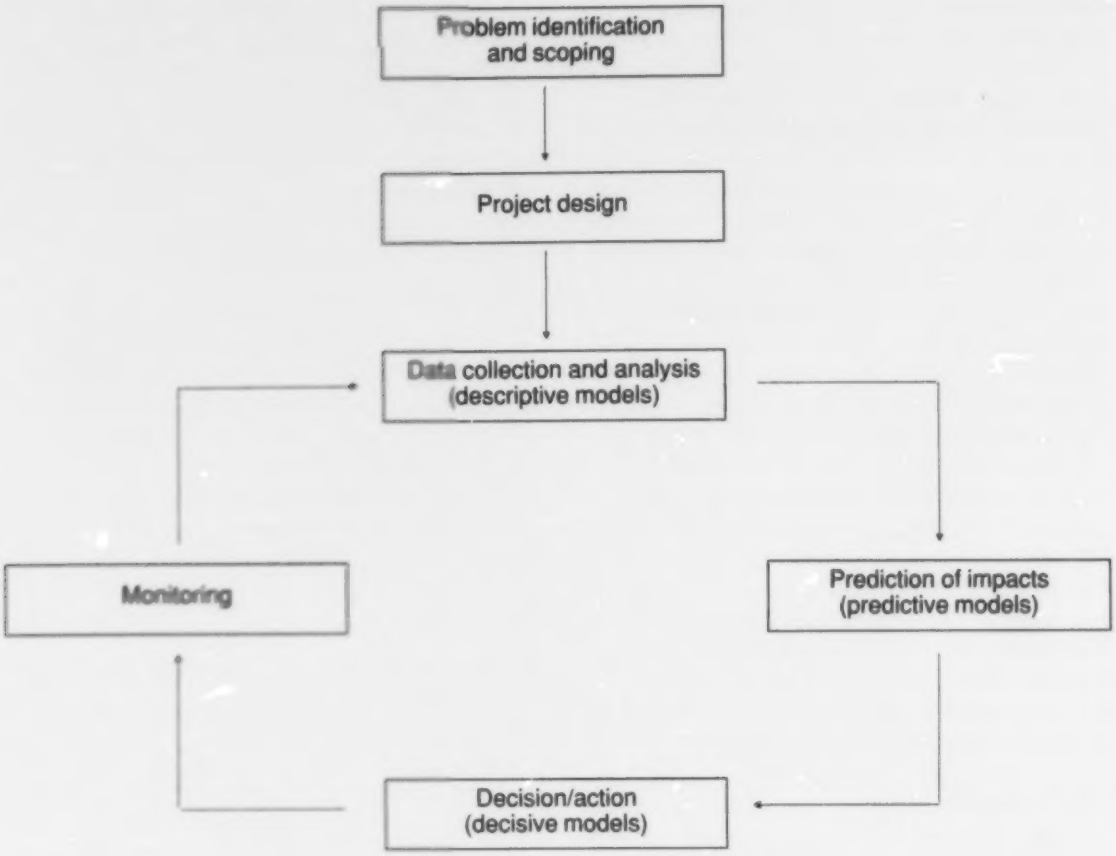

Figure 5.1:
Descriptive, predictive, and decisive models

by truck. On the basis of this prediction, access by helicopter is selected as the preferred mode of transportation.

Each type of model has characteristic attributes. A model can be static (steady state) or dynamic (changing), deterministic or stochastic (e.g., the degree of probability associated with the way in which the information is portrayed), and holistic or reductionistic (scale and scope of the data) (Gélinas 1986, 1988). In the final analysis, however, a good model is simple (Bunnell 1974), obscures incidental detail (Chorley and Haggett 1967), and assists in addressing the fundamental aspects of reality.

Software

Models are only as good as the data and information used to create and employ them. As well, and as described in earlier chapters, difficult decisions often must be made about the use and integration of the data and information. Data can be numerical for statistical analyses, textual, graphical, and spatial (e.g., employing Geographic Information Systems--GISs), all of which can play a useful role in the development and application of wildlife management models. Software for applying these different types of data and information generally has been developed independently in response to specific objectives (Peterson and Matney

1986), but many companies now offer integrated packages.

Application programs assist in data and information management by allowing the user to design and implement programs to meet specific needs. **BASIC**[1], **FORTRAN**, and **COBOL** are three of the common languages available. For example, Eng and Stelfox (1988) employed **BASIC** to develop and apply moose and woodland caribou habitat evaluation models in Alberta, while Grier (1980a,b) used **BASIC** to write a population dynamics model for the Bald Eagle. Commercial software also includes programs for statistical analysis (e.g., **SAS** and **SPSS**), word processing (e.g., **Word Perfect** and **Applewriter**), graphics (e.g., **Harvard Graphics**), data base management (e.g., **dBaseIV** and **Oracle**), and accounting procedures through spreadsheets (e.g., **Microsoft Excel** and **Lotus 1-2-3**). Many government agencies also have developed programs for use by government, academic institutions, and the private sector.

Statistical applications

Few wildlife-related studies are complete without some form of statistical analysis, which is a tool to assist in describing natural resource properties such as a wildlife population (descriptive statistics) or inferring the degree (inferential statistics) of validity of a theory or hypothesis about a wildlife population (West 1986). **SPSS** and **SAS** are two of the most powerful general purpose statistical software packages available. In addition, many other discipline-specific packages are available. Giles (1990), for example, reported on a software package written in **BASICA** for IBM-compatible microcomputers, that contains 60 small programs enabling such tasks as statistical analyses, computation of wildlife habitat edges, and estimation of wildlife populations.

Statistical procedures now available are quite varied, and the user can encounter a plethora of statistical pitfalls through improper application of a statistical procedure. Statisticians can assist in the selection of the appropriate statistical procedures and software for design and analysis of data. Capen (1981) and Verner *et al.* (1986) provided excellent commentary on the use and abuse of statistics in wildlife habitat management studies. Green (1979) provided an excellent review of the principles of statistical applications in resource assessment, while West (1986) is recommended for beginners.

Spreadsheets

Each spreadsheet package possesses unique functions and storage capabilities. For example, **Microsoft Excel** provides the ability to make projections and calculations, to complete data analyses through worksheets, manage databases, create uniquely tailored programs, and to perform certain statistical functions including averages, sums, maximum-minimum calculations, and variance (Microsoft Corporation 1987).

Eedy *et al.* (1986) used a spreadsheet program to model radiological impacts resulting from isotope disposal in municipal waste systems in Southern Ontario. Silvert (1983) used the **SuperCalc** spreadsheet program to generate a wildlife population model and promote the use of the spreadsheet procedure as a teaching tool. Olsthorn (1985) used the **Multiplan** spreadsheet program to construct ground water models, and suggests

[1]The use of trade, firm, or corporation names in this publication is for the convenience of the reader and does not constitute endorsement.

that spreadsheet programs are "...forerunners of new general software...suitable to do almost any job, where only the fantasy of the user limits the possibilities." Gray and Keith (1988) employed the **Appleworks** spreadsheet program to complete a preliminary moose habitat evaluation model for Nahanni National Park Reserve, Northwest Territories.

Text and graphics

There are many word processing and graphics packages. Data management (e.g., **Microsoft, Excel**) and statistical packages (e.g., **SAS** and **SPSS**) often contain a graphics package, but quality and flexibility vary significantly. Some word processing packages, such as **Word Perfect**, allow graphics prepared with **Harvard Graphics**, for example, to be imported and incorporated into the text.

Data base management

In essence, a data base manager is a repository or bank where the resource manager can store, organize, retrieve, and manipulate data and information. Most successful data base managers offer significant flexibility by allowing the user to design the data base format, and some (e.g., **dBase IV**) allow the user to write programs to extract specific types of data and information and complete programmed calculations. The **Reflex** data base manager allows data and information to be examined and displayed in form, list, graphic, crosstab, and a report formats. Often the data base manager can function as a powerful "intermediate" tool whereby stored data are exported to application-specific software such as sophisticated statistical packages or **GISs**.

Resource management

Numerous resource management modelling packages are now available for use on microcomputers. Mangus (1990) reported on the wildlife habitat evaluation and management modelling software which contains an accounting program (see Hays 1985) to assist in computing input values for application of the wildlife **H**abitat **E**valuation **P**rocedures (**HEP**) (see U.S. Fish and Wildlife Service 1980a) and the mathematical models to compute the **H**abitat **S**uitability **I**ndex (**HSI**) values (see Hays 1987) for selected wildlife species (see U.S. Fish and Wildlife Service 1980b). **HSI** models predict habitat quality under existing or projected conditions. This software is flexible in that existing models can be modified for species for which habitat suitability indices have not been calculated. A third component of this package, the **H**abitat **M**anagement **E**valuation **M**ethod (**HMEM**), allows the transfer of habitat models from the HSI software to management activity models which, among other things, specify the constraints and unit costs of a selected activity. The package also contains a **H**abitat **M**odel **R**eference **L**ibrary (**HMRL**) (see Hays 1989), which is an electronic bulletin board with a message facility and database capabilities which can be accessed for information on habitat models and the use of the **HEP**s (Mangus 1990).

Habitat suitability models have been under development in Alberta for several years (Eccles and Stelfox 1985, Eng and Stelfox 1988, Stelfox 1988, O'Leary 1990), for such species as moose, mule deer, white-tailed deer, woodland caribou, elk, fisher, coyote, lynx, ruffed grouse, and sharp-tailed grouse. A number of readily identifiable parameters (e.g., physiognomic structure of vegetation and terrain type) were used to evaluate food and cover requirements. This procedure allows flexibility in managing and manipulating large data bases (O'Leary 1990).

Many population models also exist or are being developed. Grier (1980a,b), for example, used **BASIC** to construct deterministic and stochastic models for small populations of animals (e.g., the Bald Eagle and Peregrine Falcon). Similarly, Reed (1990) constructed a model comprising three parameters (population size in spring, percentage of juvenile geese in the fall, and

the numbers harvested annually by hunters over the last 20 years) to simulate the growth of a Greater Snow Goose population. The model is stochastic and can be used to simulate scenarios of future population levels and how population size responds to various harvest and/or reproduction rates. It currently is not capable of predicting complex scenarios, but is being updated (Reed 1990). **POP-II** is commercially available, and contains menu-driven software for simulating mammal populations and for tracking populations through a biological year (Fossil Creek Software 1990).

Three models, written in **BASIC**, for use on IBM-compatible microcomputers were developed to simulate the energy and growth characteristics, as well as harvest rates, of the Porcupine Caribou Herd which migrates between the Yukon, Alaska, and the Northwest Territories (Russell 1990). Variables for the energy model include diet constituents, biomass of major forage, nutrient content of the forage, and feeding rates. The model predicts daily metabolizable energy intake for an individual caribou (see Kremaster *et al.* 1989). Daily growth of cows and calves is simulated over 15 life-cycle periods using daily metabolizable energy intake (from the energy model), activity budgets, and climatic factors such as snow depth (see Hovey *et al.* 1989a). The last model in this sequence simulates population levels over five life-cycle periods (see Hovey *et al.* 1989b).

To measure the cumulative impacts of timber harvesting, mining and other land use activities on grizzly bears in the United States, inter-agency teams constructed **C**umulative **E**ffects **A**ffects **A**ssessment (**CEA**) models within an integrated framework (Richardson 1990). Output is derived from interacting sub-models for habitat, displacement, and mortality, which are used to integrate variables deemed to be significant to bears. For example, the habitat and displacement sub-models are used interactively to measure habitat effectiveness, while the mortality sub-model provides a mortality risk index (see Weaver *et al.* 1987). Habitat effectiveness indirectly measures capability of an area to provide habitat (habitat sub-model), which is then adjusted with disturbance factor information (disturbance sub-model). This model assists in evaluating project alternatives and monitoring habitat conservation goals (Richardson 1990).

The government of New Brunswick and Wildlife Habitat Canada initiated a project in 1985 to develop a model to integrate wildlife habitat management concerns with forest management planning (Patch 1987, Sullivan 1989). **H**abitat **S**upply **A**nalysis (**HSA**) is used to predict the future availability of habitat (Patch 1987). The model employs wood supply analyses to forecast the availability of forest stands which provide habitat for selected wildlife species. The **HSA** models are similar to the **HEP** models, and comprise a series of tables and graphs or equations which express the suitability of forest stands to provide habitat for a selected wildlife species. The model is being tested on an 83 km^2 area where field staff assess the ability of a forest stand to provide habitat (e.g., summer food and winter cover) on the basis of vegetative structure. A wood supply model is used to monitor forest class availability through time for input into forest cutting plans (Patch 1987). A preliminary set of habitat relationships for 15 wildlife species, a computerized data base, habitat validation procedures, and confirmation of habitat forecasting techniques have thus far been developed. **HSA** eliminates wildlife as a significant management constraint, and provides managers with the necessary tools to meet feasible land use (forest) management objectives (Patch 1987).

Planning models include the **I**nteractive **P**olicy **A**nalysis **S**imulation **S**ystem (**IPASS**), which is used to forecast changes in the economy in conjunction with changes in supply and demand associated with various policy alternatives, and allows the introduction of changes in selected

parameters based on different assumptions about prevailing socio-economic conditions such as market and employment parameters (Maki *et al.* 1985, Olson *et al.* 1984). Maki *et al.* (1985) employed **IPASS** to examine the importance of forest resources to the pulp-and-paper and tourism industries in Alaska. They modelled the socio-economic impacts resulting from the simulated closure of two pulp mills, the impact on Alaska's economy of increased tourism expenditures, and the economic impact caused by the coincidental closure of two pulp mills and increased tourism.

Australia's land use program includes a planning process complemented with a computer program, **LUPIS** (**L**and **U**se **P**lanning and **I**nformation **S**ystem) (Ive 1990). **LUPIS** supports tactical land management decision-making through the use of a decision tree model, a rating and weighting model, or a combination of both (Ive *et al.* 1989). **LUPIS** has been developed for IBM-compatible microcomputers and is programmed in **QuickBASIC** (Ive 1990).

Spatial data

Maps are often an integral part of resource management, but they are awkward to use and difficult to update and manage. Geographic Information Systems (**GIS**s) have been developed for automated processing of geographic data. **GIS** encompasses a broad range of systems, from the simple electronic planimeter to a comprehensive computer-based system (Crain 1987). Conceptually, a **GIS** data base contains layers of different types of data which have been registered to a common geographic referencing system (e.g., latitudinal and longitudinal coordinates). It assists in the collection, storage, management, retrieval, transformation, and display of spatial data. A **GIS** can be used to manipulate data very quickly and many management scenarios can be established, tested, and either accepted or rejected in a short period of time with ease and accuracy. **GIS** output consists of maps and/or tables. For example, a map can portray where proposed land-uses might impact on wildlife, while a table can depict, for example, the quantity and type of habitat which might be lost or degraded.

Benefits of a **GIS**, include:

- consistency in the storage and analysis of data,
- the ability to generate reproducible results by independent operators,
- easy re-interpretation of data,
- easy file updating,
- flexible application of large and complex data sets,
- efficient completion of modelling studies for "what if" questions,
- efficiencies in financial cost and time, and
- production of high quality graphic output (Crain 1987, Lunt 1989, and others).

A **GIS** can be used to update maps, which helps to provide the most current data and information for decision-making. This is particularly important when dealing with issues relating to current suitability (as opposed to capability) of the land for a particular purpose. The **GIS** also contains powerful analytical (e.g., identifying quantitative relationships among resource sectors) and modelling capabilities (Bastedo 1986). It can link maps to tabular and textual attribute data and manipulate graphical, numerical, and textual data in a variety of combinations to generate the information used in decision-making. **GIS** is used by most natural resource management disciplines, including wildlife management and environmental impact assessment (Table 5.1).

The mandate of the U.S. Forest Service is broad and includes wildlife habitat, mining,

Table 5.1:
Examples of GIS applications in resource management

Task	Description	Source
Planning, designing	• Black-tailed deer and forest management on Vancouver Island • PAMP and ARC-Info	McNay and Page 1988
Monitoring	• Geo-referenced fur harvest and white-tailed deer survey using stratified block analysis	Kansas and Usher 1988
Monitoring	• Habitat evaluation models for moose in Nahanni National Park, N.W.T. • SAS and Tydac SPANS	Gray (in prep.)
Prediction	• Time-sensitive habitat supply analyses using various timber harvest scenarios • ARC-Info	Kansas and Usher 1988
Monitoring	• Describe Canada's biological diversity of birds and mammals according to ecoregions • Tydac-SPANS	Desrochers and Lash 1990
Planning	• Management of animal habitat data for the State wildlife agency • GEOSCAN	GEOSCAN 1984 (see Lyon 1989)
Diagnostic evaluations	• Investigated summer habitat selection by mule deer • ARC/Info resides in the Arizona Land Resource Information System (ALRIS)	Haywood 1989
Planning	• Used to integrate wildlife habitat attributes into an ecological land classification for planning • ARC-Info GIS software to examine the applications of GIS to a HEP model	Herbig 1988
Planning	• Timber harvest planning, critical wildlife habitat protection, and road planning	Hart *et al.* 1985
Monitoring	• Tested the capabilities of the MIRIS GIS • Calculation/display of Habitat Suitability Indices	Donovan *et al.* 1987
Prediction	• Predicts habitat: Curlew, Golden Plover, and Red Grouse • A variety of computers and software including a GEMS image processor and ERDAS to complete Landsat image processing	Aspinall 1990
Prediction	• Predicts the distribution of red deer in Scotland • Raster-based • GEMS image processing unit as above	Aspinall (in press)
Prediction	• Kangaroo distribution in relation to climate • Inductive modelling and mapping	Walker and Moore 1988, Walker 1990

recreation, timber harvest, endangered species management, range management, and archaeological site protection and management (Aronoff 1989). As such, complex land-use issues must be addressed, for which **GIS** becomes a logical tool. The **GIS** developed for the Flathead National Forest, Montana, for example, contains data on terrain, vegetation association, timber data, land types, land ownership, administrative districts, precipitation, and drainage data (Aronoff 1989). Hart *et al.* (1985, in Aronoff 1989) used this **GIS** for critical wildlife habitat protection and road planning.

Although wildlife-related **GIS** applications are in their infancy in Canada, some projects have been initiated. The British Columbia Ministry of Environment and Parks and the Ministry of Forests and Lands provide at least four examples of **GIS** projects (Kansas and Usher 1988). These include: coastal grizzly bear management in timber extraction areas, ungulate capability mapping for regional planning, integration of black-tailed deer and forest management on Vancouver island (see McNay and Page 1988), and analysis of land use issues with potential impact on wildlife (including fish) habitat.

Alberta Government staff used a **GIS** to display the distribution and harvest rates for squirrel, marten, beaver, lynx, and cougar according to four classes, ranging from high to no harvest. In a white-tailed deer study, a habitat classification map was developed for a selected area on the basis of vegetation, which provides food and cover. These areas were then ranked and displayed according to their predicted ability to support one of four classes of habitat ranging from high (class 1) to poor (class 4) (Kansas and Usher 1988).

Desrochers and Lash (1990) used **SPANS**, a micro-based **GIS**, to portray Canada's biological diversity with a "species richness index." A total of 386 bird species and 126 mammals were assigned to the appropriate ecoregion(s) and the **GIS** was used to generate maps of ecoregion species richness.

Expert systems

A "perennial dream of human beings has been to develop a thinking machine that can mimic human behaviour in the process of carrying out complex tasks" (Kourtz 1990). Conventional computers can process large volumes of data only using step-by-step procedures to complete a pre-determined task or meet an objective (Harmon and King 1985). Since the 1940s, a few computer scientists have been developing a computer language which allows computers to mimic human thought processes (Harmon and King 1985, Kourtz 1990). This language has come to be known as artificial intelligence (AI).

By the mid-1960s, Edward Feigenbaum and his associates were able to encode human knowledge in a symbolic nomenclature, usually English words (Kourtz 1990). An exact definition of artificial intelligence is elusive, but most centre around the concept of knowledge, its acquisition, representation, and use to solve real-world problems (Kourtz 1990). AI involves flexible responses, an ability to make sense out of uncertain, incomplete, or contradictory messages, and an ability to recognize the relative importance of the different elements of a situation (Hofstadler 1980). It blends cognitive psychology and computer science to make computers "smarter" and more useful, and capable of doing things that, at present, humans can do better (Rich 1983) (Table 5.2).

Sub-disciplines of AI include: development of natural language processing, speech recognition, learning, and computer vision; robotics; and expert systems (Harmon and King 1985). Although all three have uses in natural resource management, most work to date has been on the development of expert systems, which is the focus of this section. Knowledge-based expert systems are, in

Table 5.2:
Comparison of conventional programming with expert system programming[1]

Conventional programming	Expert system
• Task previously performed by humans, commonly with little expertise, but according to the instructions of experts	• Task previously performed by a human expert
• General and broad applications	• Normally a narrow subject area
• Maintained by specialized programmers	• Maintained by knowledgable engineers and experts
• Often difficult to read and modify	• Knowledge base readable and easy to modify
• Sequential batch processing	• Highly interactive processing, and can explain the rationale that led to the solution
• Numerically structured data base	• Symbolically structured knowledge base
• Relies on algorithms for overall structure	• Relies on heuristics for structure; problems having an algorithmic or a mathematical process not suitable for expert systems
• Cannot handle uncertainty	• Includes techniques to handle uncertainty
• Tables of numbers and graphs as output	• Concrete advice as final output

[1]Adapted from Harmon and King 1985, Stock 1987, and White *et al.* 1985.

essence, a collection of AI techniques which enable computers to assist people in problem analysis and decision-making. Davis and Clark (1989) provided many excellent references.

Expert systems are computer models of expert human reasoning which differ in a number of ways from conventional systems (Table 5.2). Generally, their power and usefulness is in the knowledge base they contain and the flexible and intelligent ways in which that knowledge is employed (White *et al.* 1985). They allow resource managers to install computer-based, but human-derived, knowledge in the form of facts which are manipulated according to a set of rules (heuristics) developed for a specific task or problem solving exercise (Kourtz 1990). Thus, knowledge can be used by the resource manager to analyze an often unique situation and to generate a recommendation or solution comparable to the advice that might be provided by a human expert.

An expert system has four main components: a knowledge base, a user interface, an interface with the supporting computer operating systems (including data base structure and graphic tools), and an "inference engine" (Kourtz 1990, Rauch-Hindin 1983, Stock 1987, White *et al.* 1985) (Table 5.3). Expert systems can be employed to complete many tasks (Table 5.4) including: diagnostic evaluations, monitoring, prediction, planning, and training (Stefik *et al.* 1982, White *et al.* 1985). In wildlife management, diagnostic programs could be used, for example, in parasite and disease research and management, and population and habitat management. Planning of wildlife population and habitat survey programs is a logical expert system task as well. Expert systems can be employed to develop specific recommendations about the actions most likely to succeed; for example, they could be used to determine pesticide application strategies or the most appropriate timber harvesting techniques to enhance production

Table 5.3:
Components of an expert system

Component	Description
1. Knowledge base	• Contains facts and rules of operation • Encoded in symbolic form such as "if-then" clauses
2. User interface	• Allows user and expert system to communicate • Questions posed to, or received from, the operating software through the user interface • Usually includes features such as colour graphics, pull down menus, raster pictures, maps, voice output, and cursor control (e.g., mouse)
3. Interface with supporting operations	• Allows access to the existing supporting operations data bases
4. Inference engine	• Automatically carries out a search of the knowledge base for the appropriate facts and rules to link together to form new facts and rules that eventually lead to a decision or a recommendation • Interprets the knowledge base and performs logical deduction and certain knowledge base modifications in support of a decision

[1]After Harmon and King 1985, Kourtz 1990, Rauch-Hindin 1983, Stock 1987, and White *et al.* 1985.

of wildlife habitat. Interpretation programs have also been adapted for deer-forest management in British Columbia (McNay *et al.* 1987). All expert systems can be used as training tools .

Expert systems have been developed and applied to GISs for map design, geographic feature extraction, and geographic decision support (Robinson *et al.* 1987). Some of the most promising applications of integrated GIS-expert systems lie in the development of intelligent user interfaces, efficient spatial database search techniques, improved image classification, and production of high quality cartographic products (Robinson *et al.* 1987).

A number of general advantages of expert systems include: a knowledge base derived from more than one expert, consistency (i.e., no sick days or periods of low productivity), total recall (White *et al.* 1985), and easy user access to the rationale behind the predictions being made (Hurley 1986). Expert systems are particularly useful for the natural resource management disciplines where knowledge (e.g., biological knowledge) is often symbolic (as opposed to numeric) (Olson and Hanson 1988). Limitations include: generation of incorrect decisions and questionable advice requiring implementation of a comprehensive audit process, and the lack of knowledge (particularly about ecological systems) (White *et al.* 1985).

Concluding remarks

The management and exchange of data and information are critical for simultaneously meeting the needs of government agencies, the private sector, and the general public. In this context, the development of computer technology for data collection, storage, analysis, interpretation, and presentation has enhanced the ability of wildlife managers to meet demands for rapid and effective access

Table 5.4:
Examples of expert systems developed for applied decision-making

Task	Description	Source
Prediction	• A moose management expert system • Specific harvesting strategies can be examined to predict the impact of moose populations on conifer regeneration • Integrated with a GIS, rules to simulate hourly behaviour of moose and forest growth and harvesting models • LISP machine and expert system development kits	Kourtz 1990
Diagnostic evaluations	• An aquaculture decision and fish disease diagnostic expert system • Constructed within a commercial shell	Kourtz 1990
Planning and training	• Black-tailed deer/forest relationships • "The deciding factor" • A package which develops a heuristic framework for the decision-maker through an editor	McNay *et al.* 1987
Planning and training	• Black-tailed deer/forest relationships • PROSPECTOR II	McNay *et al.* 1987
Prediction	• Moose/forest dynamics • Symbolics 3640 computer and prototype in LISP • Employs an expert shell (KEE)	Saarenmaa *et al.* 1988
Planning	• A silvicultural advisor for Ruffed Grouse and white-tailed deer • CHAMPS Expert System	Buech *et al.* 1990a and 1990b
Prediction and training	• Two expert systems to predict presence of bird species in a brushfield habitat following clearcut logging in a coastal forest in California • BRUSH written in BASIC for use on an IBM PC • GUILD written in LISP (dialect ALISP) on a CDC Cyber 170/720 mainframe	Marcot 1986

to data and information, and to make the decisions associated with the use of the information. The contemporary wildlife manager now has access to an impressive array of powerful, user-friendly microcomputer-based tools which can be used to aid wildlife management. But selection of the most appropriate software (not necessarily the most expensive or powerful) is critical, and it is recommended that, wherever possible, the resource manager pay particular attention to, and seek expert advice on, the software to be employed in the implementation and maintenance of data and information management strategies.

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6. The application of ecological theory to ecological land surveys and wildlife and habitat evaluations

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Introduction

As resource development and urbanization progress, the availability of wildlife and their habitats is constrained. It is becoming increasingly important to accurately identify and comprehensively characterize wildlife resources. Ecological land survey (ELS) is becoming progressively accepted as a means of accomplishing this task (McClure *et al.* 1979; Prescott 1980; Stelfox 1980). Critical to this effort is the need to determine the types of environmental descriptions that must be measured in ELSs (Hirsch *et al.* 1979). Ecological theory provides a framework within which to acquire and organize the empirical survey data (Hoekstra and Flather 1986).

Neither survey data nor theory is necessarily a truer representation of nature than the other; however, through comparison, they improve our understanding of the environment.

A basic premise of this manual, in terms of both ecological theory and ELS data and information, is that land and water resources operate as systems (as opposed to independent parts). The following theoretical framework begins with *niche* theory, which defines and characterizes the environment for an individual animal, a population, or a community. *Island biogeography* theory incorporates spatial factors and adds insight into surveys design. *Succession* theory provides additional insight into survey design by providing a basis for scheduling to capture the temporal dynamics of ecological systems. Finally, *hierarchy* theory considers ecological systems at different levels of generalization (e.g., individual, population, community, as well as levels of classification(ELC)/ mapping); and provides a basis for determining the relationships between levels.

The development of this chapter was guided by the question: "What are the quantities and characteristics of the wildlife resources contained in a multiresource system?" The application of ecological theory is, therefore, directed at a comprehensive survey and inventory of wildlife resources.

Niche theory

Background

Niche theory defines the environmental characteristics that permit an individual or population to exist within a community at a particular time.

Although niche is defined in terms of the total environment, this discussion is organized into intraspecific and interspecific considerations.

The historical development of the niche concept has generated some confusion. Grinnell (1917) and Elton (1927) appear to be the first investigators to use the term in the ecological literature. Grinnell perceived niche as a spatial subdivision of the total environment that was used by a species. Elton, on the other hand, described niche as

an organism's functional role in a community, a perception that was reinforced by Odum (1959) in his analogies of niche/profession and habitat/address. Gause (1934), during his investigations into competition, argued that no two species can occupy the same niche--the competitive superiority of one species must ultimately result in the exclusion of the other.

Hutchinson (1957) integrated the structural/functional dichotomy established by Grinnell and Elton as a multidimensional description of the environment. Each dimension represented a gradient (e.g., temperature, elevation, food size, vegetative cover) characteristic of that particular environment. A niche was defined for a species by integrating tolerance zones or resource use spectra over each gradient.

Whittaker *et al.* (1973) distinguished between habitat and niche variables. Habitat variables are extensive, intercommunity variables, such as elevation, aspect, vegetation type, and type of surficial deposit. In contrast, a niche is described by intensive, intracommunity variables, including density of stems, canopy cover, and food size.

Despite the attempts to clarify the niche concept, it still suffers from misinterpretation and a profusion of terminology. However, the concept of niche offers a basic framework for determining variables in ELSs--a method that is predicated on holism. Niche theory also offers a unifying principle whereby intraspecific and interspecific relationships within a community can be examined simultaneously.

Intraspecific relationships

One aspect of niche theory focuses on life requisites regardless of the interacting species of the faunal community (e.g., competitors, predators, and cooperators). This conceptual isolation of a species is referred to as intraspecific niche relationships. Intraspecific relationships rest largely on an understanding of population dynamics. The logistic model assumes that population growth is proportional to the population size in relation to some limiting capacity (k), which is specific to a particular environment (May 1981). This translates graphically into the sigmoid growth curve (Figure 6.1). Observed fluctuations of populations relate to a complex of biotic and abiotic limiting factors (Johnson 1977). As Leibig described in 1840, the rate of biological process (in this case population growth) is limited by that factor in least supply (Elseth and Baumgardner 1981). This implies that an increase in the availability of a limiting factor will result in a monotonic increase in the population until another limiting factor is encountered.

An extension of Leibig's ideas involves considering the situation in which an excess of certain factors can also limit populations (Figure 6.2). Shelford (1913) proposed that the population growth for a species at a particular time is directly related to its range of tolerance for given environmental factors. The unimodal curve defines zones of intolerance, physiological stress, and optimal adaptation. The relationship to niche theory becomes apparent when a number of environmental gradients are examined in concert. Integration of several environmental factors results in areas of tolerance or resource use. Hutchinson (1957) used this multidimensionality of the tolerance concept in his definition of niche. Optimal conditions for reproduction or survival are centrally located, with the niche boundary defining the distribution limit of the species (Hutchinson 1957; Whittaker *et al.* 1973). Consequently, density tends to decrease from areas of optimal suitability (Andrewartha and Birch 1954; Wynne-Edwards 1962). Although this pattern appears to hold in general (Partridge 1978), the relationship between density and habitat quality must be examined carefully. Intraspecific interactions may result in higher densities of animals in suboptimal habitat by forcing individuals to move from optimal areas during highly productive years (Van Horne 1983).

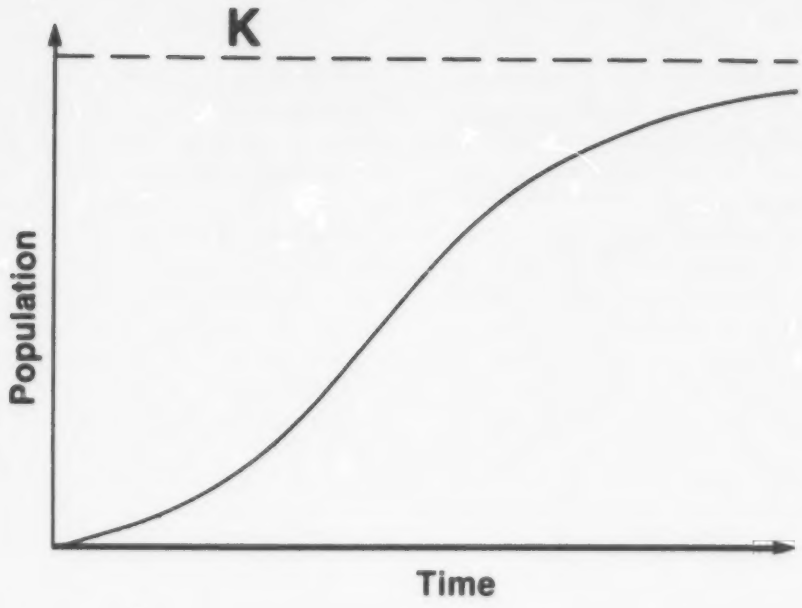


Figure 6.1:
Sigmoid growth curve of a population

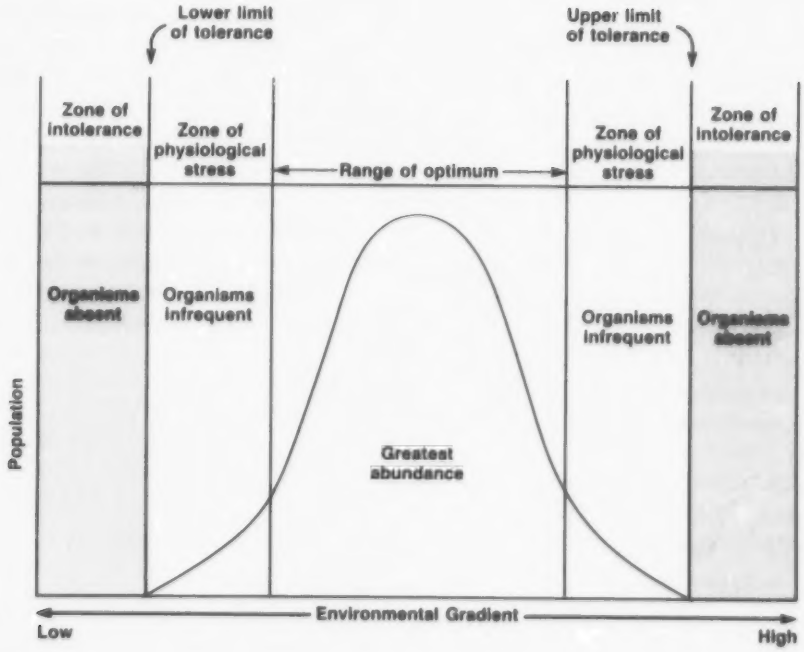


Figure 6.2:
Shelford's law of tolerance, illustrated graphically (adapted from Smith 1974)

Interspecific Relationships

That a species cannot exploit the entire range of resources defined by its genes is an accepted ecological principle. In reality, competitors, predators, or other coexisting species tend to restrict the amount of space used by a species. We refer to this as interspecific niche relationships.

Gause's (1934) competitive exclusion principle states that no two species can occupy the same niche and continue to coexist (Elseth and Baumgardner 1981). It has been assumed that the observed segregation of species along a particular gradient is the result of competitive exclusion. Colwell and Futuyma (1971) exposed a logical inconsistency with this assumption by arguing that niche overlap can support or refute the existence of competition. Competitors are thus perceived as achieving coexistence through evolutionary differentiation in resource uses so that niche overlap is compatible with the particular resource base.

Although niche theory has been formulated around the premise that competition is the primary process in structuring animal communities, there is evidence that predation is an important interspecific interaction in constraining the niche of a species (MacIntosh 1980). Paine's (1966) study of intertidal communities suggests that predators are the primary factor responsible for permitting the coexistence of ecologically similar species. Predators constrain the niche of competitively superior prey species, thereby allowing the existence of competitively inferior organisms (Schoener 1982). Nelson and Mech (1981) provided empirical evidence of the influence of wolf predation on the distribution and abundance of white-tailed deer.

Despite the ecological importance of interspecific interactions in affecting the distribution and abundance of a species, there has been little success in applying such concepts in predictions of habitat value. Changes to the faunal composition of a community (e.g., elimination of the top carnivore) could result in alterations of the environmental relationships among the remaining animals. Also, apparently similar vegetative communities can have different faunal components (Schaffer 1981), which will also alter the expected environmental relationships. There have been some attempts to include interspecific variables in the description of a niche. However, difficulties associated with accurate representation of interspecific relationships have precluded their inclusion in most evaluations of wildlife habitat. Carey (1981) included the presence of competitors as a niche dimension and found significant relationships for certain species. Similarly, Diamond (1975a) and Haefner (1981) developed community assembly rules that take into account incompatibility between certain species.

Island biogeography

Background

Island biogeography theory focuses on translating the environmental tolerance of a species, defined by niche theory, into the effects of habitat size, shape, and distribution for populations and communities. At the faunal community level, the biogeographic concept identifies the degree to which a group of animal species is unique relative to surrounding communities; at the population level, consideration is directed at the ecological conditions needed to maintain viable populations of individual species.

Community aspects

The island biogeography concept developed through attempts to quantify the spatial distribution of occurrence and abundance defined by:

$$S = CA^z$$

where S is the number of species, A is the area, and C and z are dimensionless parameters whose values need to be fitted for each set of species/area data. Data obtained from field samples on numbers of individuals

or numbers of species are summed in relation to the increasing number of sample areas and, when plotted, demonstrate the biogeographic effect of sampling communities (Figure 6.3). Linear regression of log-transformed data (Figure 6.4) permits the calculation of C and z where

$$\log S = z \log A + \log C$$

Although this power function describes many species-area relationships, there are exceptions (May 1975). Preston (1962a, 1962b) showed that the slope (z) of the species/area relationship could be used to reflect the extent to which a land area is complete or part of a larger ecological community. The general application of Preston's theory was empirically examined by MacArthur and Wilson (1967). Their work demonstrated a basic rule for interpreting the z value: for samples of communities, z was shown to be 0.12-0.17 and for entire communities, z was 0.18-0.35. Calculation and interpretation of the z value would thus be useful in describing the degree to which a land unit can be considered to represent an entire community or, alternatively, a sample of some larger community (also, a measure of the land unit's uniqueness relative to its surroundings). Hagmeier (1966) applied this logic to define mammalian provinces for North America. His analysis was based on Preston's (1962a, 1962b) determination that values of z around 0.27 represented the threshold between faunal homogeneity and heterogeneity.

Diamond and Mayr (1976) demonstrated that caution is necessary in interpreting a z value--communities can behave as samples in response to the loss and fragmentation of habitat. Identifying true colonists when dealing with vagile species contributes to the problem. Inclusion of vagrant and transient species in analyses will elevate diversity and turnover measures; this is of particular concern in an analysis of habitat "islands," as the probability of observing vagrants is higher than on true islands (McCoy 1982).

Speciation processes, as related to island size, age, and isolation (described by Darwin), and the colonization/extinction process (described by MacArthur and Wilson) are the principal mechanisms that determine the vertebrate composition of oceanic and inland islands. In the MacArthur-Wilson equilibrium model, colonization rate varies inversely with distance to a source of dispersing species, and extinction rate varies inversely with island size (Figure 6.5). In addition, Brown and Kodric-Brown (1977) obtained empirical evidence that insular extinction rates also depended on the distance of an island from the source of colonists rather than solely on island size, as assumed by the MacArthur-Wilson model.

The rates of colonization and extinction processes occurring within a habitat unit vary directly with how long the unit had been unique, its size relative to surrounding habitats, and its distance from other similar habitats in the regional ecosystem. This leads to an important implication for applying these principles in terms of how human activities result in habitat fragmentation or isolation, which changes the equilibrium level that was established prior to the disturbance. Wilcox (1980) considered habitat fragmentation to have two components: habitat loss, and insularization. Habitat loss eliminates some of the original vertebrates and increases the extinction rate of those that remain. Insularization of habitat can eliminate species within it by altering the environment surrounding it (i.e., creating islands) reducing the opportunity for potential colonists to have access to it (i.e., creating barriers).

The equilibrium number of species on islands also has been postulated to be a function of shape. Although conclusive evidence is lacking on the significance of shape, further evaluation of colonization and extinction rates is needed.

Population aspects

Although the colonization/extinction processes described by the MacArthur-Wilson

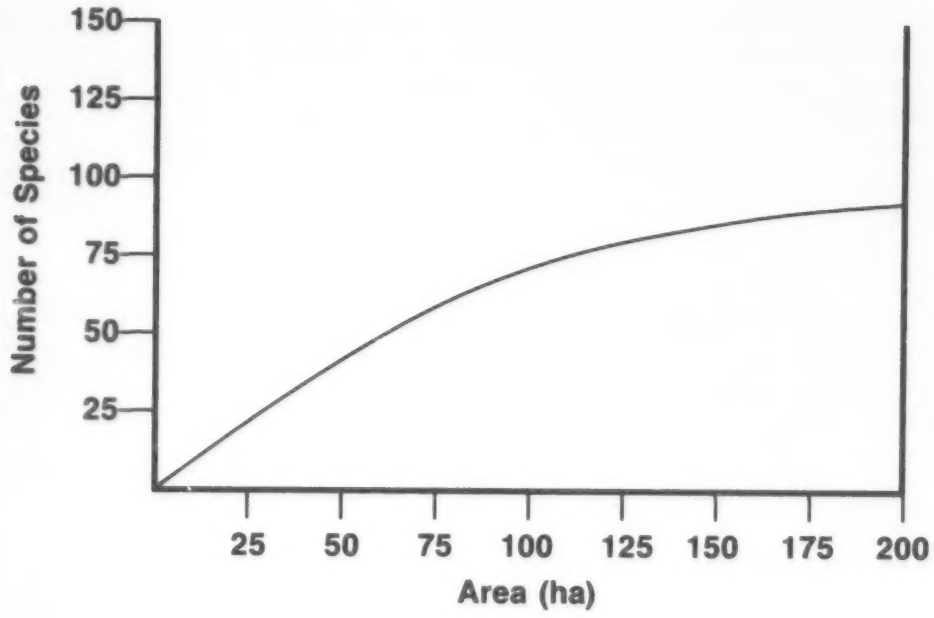


Figure 6.3:
The general relationship between habitat area and species richness: the biogeographic sample effect

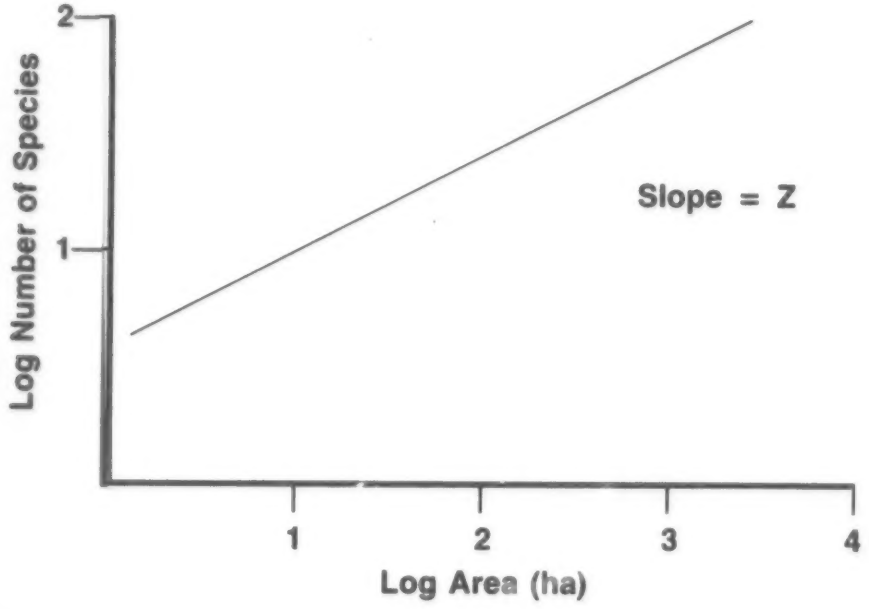
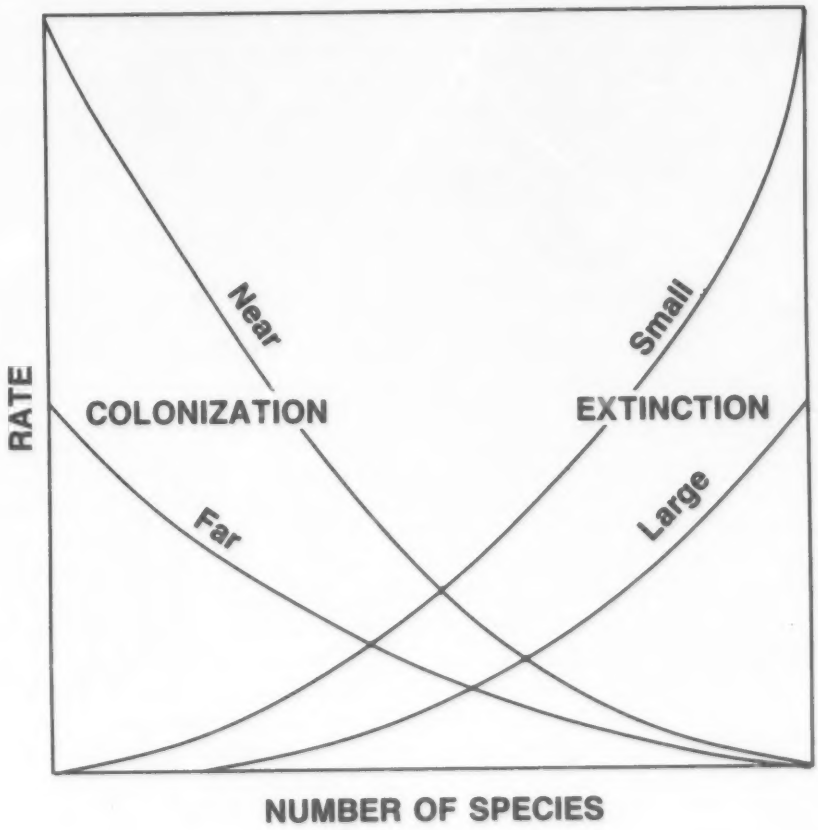


Figure 6.4:
The species-area relationship plotted on logarithmic axes: log s = z (log a + log c)

Figure 6.5:
The MacArthur-Wilson equilibrium model of island biogeography



equilibrium model focus on community dynamics, the theory has also been applied to populations of individual species. Both the size and distribution of habitats are of interest, particularly for species that depend on habitat size.

The concept of dependency on habitat size has emerged from species/area relationship studies and the observed loss of species in localized habitats. Different species usually have different area requirements for survival based on different rates of immigration and extinction (Diamond 1975b). Galli *et al.* (1976) and Robbins (1979), respectively, found that nearly 50% of the birds breeding in New Jersey mixed-oak patches and Appalachian forests depended on habitat size. Similarly, Samson (1980) reported that nearly two-thirds of the birds breeding in tall grass prairies depended on habitat size.

Based on the studies reported above, the relationship between inter-habitat patch distance, habitat patch size, and the percentage of habitat patches occupied must be determined empirically for each species. In general, the nature of the relationship shows that increasing habitat patch occupancy is inversely related to inter habitat patch distance and directly related to habitat patch area.

The empirical data needed to evaluate the colonization/extinction relationship of habitat patches include the recognizable description

of habitat patch and the geographic data on size and distance between similar habitat patches. Demographic data include the population density, birth rate, and death rate; these can be approximated from previous studies on the species if occurrence in habitat patches cannot be verified.

Succession theory

Background

The discussion of ecological theory has thus far focused primarily on spatial aspects of animal distribution and abundance. However, an animal's environment is not static but rather temporally dynamic. Vegetation changes that accompany alterations in the other ecosystem components (e.g., faunal composition and soil structure and fertility) must be recognized and understood by land and resource survey specialists. An understanding of succession theory provides the basis for which changes in wildlife habitat characteristics can be anticipated and defines the time over which resource surveys must be conducted.

Early emphasis in succession focused on a description of the phenomena stemming from the observations and reasoning of geologists (Golley 1977). Clements (1916) popularized the analogy between succession and a developing organism (the "superorganism" metaphor) based on his investigations of grassland ecosystems. Classical Clementsian theory viewed succession as an "orderly and progressive replacement of one community by another" (Smith 1974), which is reasonably unidirectional and culminates in a steady state referred to as the climax (Odum 1969, Giles 1978). Alternatively, succession has been viewed as polyclimactic, with the final steady state depending upon the characteristics of a heterogeneous environment. However, Whittaker (1953) dispelled both views as unnecessary. He proposed a climax pattern hypothesis in which the climax community is not regarded as a discrete entity but rather as a continuously grading pattern. Such a perception is related to Gleason's (1926) individualistic view that the dynamics of a community must be understood by examining the dynamics of the individual species.

The incongruity between random or orderly patterns of succession is a function of both the idiosyncracies of a particular environment and the perception scale of the observer. Horn (1981), Cottam (1981), and MacMahon (1981) reviewed the characteristics of environments associated with a random versus orderly progression of sere. Allen *et al.* (1984) discussed how the apparent inconsistency can be resolved by considering the scale at which the system is observed.

Succession in relation to wildlife habitat

Succession theory does not directly address the notion of wildlife habitat but rather describes the dynamic nature of ecosystems. Succession describes the changes in environments or habitats--changes that favour some wildlife species over others. Theoretically, each successional stage can be exploited only by individuals that are adapted to the conditions particular to that stage. The resident wildlife community is determined, in part, by how well the environmental gradients characteristic of a given sere meet the niche requisites of the individual species. However, the cause/effect relationship is not unidirectional, and it would be erroneous to assume an absence of interaction between vegetation and wildlife communities (MacMahon 1981). Harper (1969) discussed an example in which herbivores can maintain in a seral condition areas that would have changed in their absence.

Giles (1978) illustrated the relationship between sere and faunal components by plotting the density of species against time. A peak density is reached at a successional stage when the niche requirements of the component species are best met. Figure 6.6a represents an early successional species in a single habitat, whereas Figure 6.6b illustrates the relationship of a "climax" species in habitats of varying suitability. Johnston and Odum (1956) showed that a successional

progression in plants was accompanied by a succession of bird species, each population peaking at a particular stage. The patterns described by Johnston and Odum (1956) and Giles (1978) presume that the site is sufficiently near a colonizing source to permit invasion when the conditions of that site meet the niche requirements of a particular species.

Hierarchy theory

Individual wildlife species depend upon a resource base that can vary from local site to intercontinental geographic scales. Ecological systems are complex, in part because they are defined at several different levels. Additional complexity becomes apparent with the recognition that ecological systems are composed of multilevel structural components, such as landforms, soils, climate, vegetation, and wildlife, which are interwoven by such processes as decomposition and growth. Hierarchy theory, as described by Allen and Starr (1982), provides the principles needed to deal with the multilevel structure and dynamics of ecological systems. Hierarchy theory uses the structure/process dualities of different ecological systems as a basis for their identification. Because the structure and processes of different ecological systems vary, ELSs have to accommodate different variables to describe them.

Ecological systems have characteristic rates of behaviour that serve to distinguish levels. Populations are initiated, expand, contract, and disappear at rates different from those of communities. Hierarchy theory contends that slower entities, those with relatively low-frequency behaviour, constrain and are the context of faster, high-frequency entities contained within them. In the case of communities (slower entities) and populations (faster entities), community structure, which is manifested as interspecific relationships, constrains populations to their realized niches. Control and order in ecological systems can be observed as a frequency-defined set of interrelationships.

A second characteristic of ecological systems, observed in the asymmetry of their rates of behaviour, is that relatively rate-independent constraints are imposed on rate-dependent processes. In a comparison of levels of communities and populations, the rate-dependent growth of a population (r) is

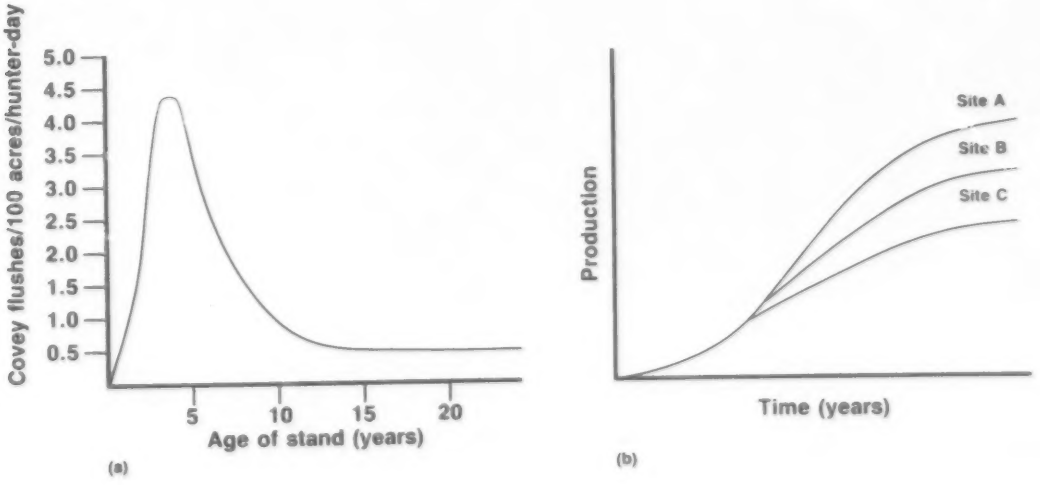


Figure 6.6:
Giles's (1978) production function concept relating wildlife production to succession. Part (a) represents an early successional species through time, while (b) represents a single "climax" species in different habitats of varying suitability

observed to be constrained by the rate-independent community carrying capacity (k). Rate-independent constraints of larger, slower systems are imposed on rate-dependent processes of ecological systems contained or nested within.

A third characteristic of ecological systems is that it is not possible to observe or determine the constraints imposed by communities on a set of population processes from the population processes themselves. A community cannot be predicted from perfect knowledge of the colonization, birth, growth, and death processes of individual wildlife species, even though these processes of the species do not violate the constraints of the community. The criteria for aggregation of populations into communities should not be expected to be the same criteria for aggregation of individuals into populations. Conversely, this principle does hold for the criteria to break down communities into populations and populations into individuals.

A fourth characteristic of ecological systems defines the concept of their surfaces. The surface of any ecological system is defined by the observed attenuation effect of external processes on entities contained within that ecological system. In the case of a community, as one views it from outside, the surface becomes tangible by observing or measuring the structure of the community (e.g., species abundance, diversity, richness, and associations) and the processes of its populations (e.g., birth, death, immigration, and emigration). Conversely, the surface of a community also can be defined by observing or measuring structure and the processes of the ecosystem within which it is contained (e.g., energy and nutrient fluxes). Surfaces of ecological systems, then, can be defined by analysis of the measured structural variables of the system and preferably the processes of both the system's environment and the system's parts.

Hierarchy theory provides the basis for stratifying ecological systems into levels of generalization. Allen *et al.* (1984) outlined the principles for defining the various levels in a hierarchy of systems as well as for moving between them. When the system level selected is a population or community, succession theory defines the rate of change, biogeography theory defines the size, shape, and distribution of the system, and niche theory provides the basic variables used to describe the system.

Implications of ecological theory to ecological land survey

Introduction

Theory, according to Romesburg (1981), is a general conjectural statement directed at explaining a process. Theory should serve as a guide within which to analyze problems and form researchable hypotheses (Nudds 1979). The application of theory here is directed at the problem of developing a comprehensive survey of wildlife and habitat in the context of ecological systems.

We have attempted to provide a logical framework upon which to base recommendations for incorporating wildlife concerns into ELSs. The reviewed theory addresses two major aspects of resource surveys. First, niche and biogeography theories provide insight into the types of variables that need to be considered in an evaluation of habitat resources. Second, biogeography, succession, and hierarchy theories provide logical support for the design of surveys through time and space. The specific implications of each concept of ecological theory to ELS illustrate more clearly their relationships to the determination of variables and to survey design.

Niche theory

Resource surveys must ensure that variables that are measured will permit the desired evaluations and analyses to be carried out. In this case, the analysis is a description or characterization of wildlife resources. Niche theory provides guidance on the general categories of environmental variables that

should be measured for a species or group of species. The specific variables that will be measured, however, will depend on the species and, to a large extent, the character of the environment for a particular area.

Shugart (1980) and Schoener (1974) presented four categories of important environmental variables: macrohabitat, microhabitat, food type, and time. This is very similar to the breakdown of important niche dimensions of Pianka (1973), who argued for measuring three variables: food type, microhabitat, and activity period. These attempts to synthesize common niche variables exemplify the types of variables that appear to be significant to a description of the environment that is exploited by a species.

Niche theory is also flexible enough in concept to be applicable at several levels of ecological generalization. Many resource management and land use planning issues do not involve or require information at levels of detail suitable for individuals or populations. Instead, they may require a more general description of wildlife habitat quality, in which the entire community must somehow be characterized according to its use of the landscape. MacIntosh (1980) viewed the community in light of niche theory as a collection of niches. Consequently, faunal communities (Matson 1982) can be hypothesized as using a multidimensional space, such as that described by Hutchinson (1957)--the difference being that the focus is on the community rather than the individual or population, which means that the variables considered may also change.

Island biogeography theory

Much of the empirical demonstration of island biogeography theory has involved the measurement of the occurrence and abundance of wildlife species, together with the parameters for describing size, shape, and distribution of habitat patches. The species/area relationship specifies that surveys of occurrence for vertebrate wildlife species are necessary to define faunal communities. Systematic samples proportional to area evaluated using log-transformed data permit estimation of the z value for samples as well as for entire communities.

Delineation of faunal communities is necessary to define the spatial framework within which to consider more specific descriptions of wildlife habitats from a population perspective. The faunal community represents the species pool for the interspecific relationships of niche theory, and it defines the realm within which to consider the three biogeographic variables that have been shown to be important in assessing habitat value. Habitat patch size and distance between similar patches are relatively straightforward survey variables. In contrast, patch shape requires a standardized unit of measure (e.g., perimeter-to-area ratio for circles, squares, rectangles, triangles, etc.). Although these are the separately measured variables, the analytical integration of these variables and their effect on colonization and extinction processes must be considered.

Island biogeography theory also provides guidance regarding resurvey based on the extinction/colonization attributes of the system. As long as a community remains in equilibrium, the original species/area relationship will be a valid basis for definition of the faunal community. However, because extinction and colonization processes are dynamic, a new species/area relationship must be obtained when the faunal community changes. One reason why extinction and colonization processes are dynamic is that long-term changes in habitat occur. Many of these changes are man-induced, including the conversion of forests and grasslands to crops or the subsequent reversion of the croplands to their natural state.

Succession theory

Succession theory provides a context within which to consider time frames over which surveys must be scheduled. These time frames can vary depending upon the level at which systems are being surveyed. If the goal

is to assess habitat quality for a species for any year, then surveys should recognize the phenological (i.e., annual succession) aspects associated with a particular landscape. Alter-natively, monitoring wildlife habitat quality over time (seral stages) will specify longer-interval surveys to monitor changes. For example, coniferous forests are typified by relatively persistent seral stages, with the result that the entire successional sequence could take centuries to complete. Conversely, succession within grasslands appears to operate over decades (MacMahon 1981).

Hierarchy theory

The principal implication of hierarchy theory to ELSs is in the identification of levels of ecological systems. Variables to be measured vary and are unique for each level of system generalization to be characterized (e.g., variables for populations, communities, ecosystems, etc.). Hierarchy theory postulates that variables for ecological systems are both structural and functional, which is consistent with niche theory and biogeography theory. Finally, hierarchy theory specifies that structural variables are those of the level of generalization being described, whereas process variables are those of the next higher and lower levels of generalization. Hierarchy theory, therefore, does not specify new variables to measure but rather rules for determining which variables are relevant to the system to be characterized.

Application of ecological theory to the definition of population-level and community-level survey variables

The ultimate objective of this chapter is to translate ecological theory into guidelines for incorporating wildlife resource concerns and values into ELSs. Initially, we posed the question: "What are the quantities and characteristics of the wildlife resources contained in a multiresource system?" That question and its possible answers are not specific to any level of ecological organization. On the basis of hierarchy theory, the question can be restated for specific levels of ecological generalization. As an example, we will address two levels (population and community), recognizing that other ecological levels are possible and interesting (e.g., individual and ecosystem). The question now is: "What is the size (numbers and biomass) of each population of wildlife species in a community?"

Before defining the input and output parameters for each aspect of the question, we must briefly look at our definition of community. In the section on biogeography theory, we defined a community to be identified by the estimation of the z value. This definition refers to an assemblage of animal species within a definable geographic area. The boundary of a wildlife community is defined by the flux in the z value away from the range of 18-35, as sample size increases. The use of the occurrence of animal species to define the community is an important distinction from the traditional use of plants.

Vegetation communities are commonly described in current ELSs. However, vegetation communities do not adequately describe the environment of a wildife community. The distinction between these types of communities is based on the principles of hierarchy theory (Allen *et al.* 1984). A vegetation community is a meaningful assemblage of plant species (based on the distribution of dominant species) in a specified geographic area with some undefinable grouping of animals present. A wildlife community, on the other hand, is a meaningful assemblage of animal species (based on distribution of species occurrence) in a specified geographic area with an undefinable group of plant species present. Vegetation and wildlife communities define different geographic entities that are not directly translated or converted into one another at the community level.

Returning to the questions posed, the answers to the population-level question must be addressed in terms of animal and habitat characteristics. The animal characteristics are

measured in terms of density or biomass; habitat characteristics are measured in terms of habitat diversity; combined characteristics of the animal and its habitat are measured by colonization and extinction rates. Answers to the community-level question are in terms of total animal biomass, species diversity, community habitat diversity, and the spatial distribution of the community.

The inputs or surveys needed to answer these questions are different for the population level and the community level (Table 6.1). In the case of both population and community, the

Table 6.1:
Survey variables defined by niche and island biogeography theory for population and community levels of concern

Level	Supporting theory	Answers/outputs	Survey variables (units)
Population	Niche	Density or biomass • Animal characteristics	• Weight (kg) • Length (fish) (cm) • Abundance (no.) • Natality (no./time) • Mortality (no./time) • Emigration/immigration (no./time) • Territory size (ha)
		• Habitat characteristics	• Food production (kg/area/year) • Climate - solar radiation (kcal/m^2/day) - precipitation (cm/year) - temperature (mean, in °C) • Competition - food lost to competitor (kg/area/year) • Physiographic relief (m)
	Island biogeography	Habitat diversity	• Structural characteristics • Area covered by habitat components (ha) • Distribution of habitat components (km) • Interspersion of habitat components (km edge/area)
		Colonization and extinction	• Animal characteristics • Natality (no./time) • Mortality (no./time) • Dispersal capability (km) • Habitat characteristics • Area covered by habitat components (ha) • Distribution of habitat components (km) • Shape of habitat components (categorical--i.e., circle, square)
Community	Niche	Total animal biomass Habitat diversity	• Species mean weights (kg) • Vegetative cover diversity (index) • Physiographic diversity (index) • Total area (ha)
		Species diversity	• Species occurrence (categorical--i.e., species list) • Species abundance (no.)
	Island biogeography	Geographic distribution of the community	• Species occurrence (categorical--i.e., species list)

concept of habitat ties the animal to the land base. The habitat parameters are surveyed and either based on or related to the ecological theory described earlier. This is the significance of the point made earlier--the animal population or community must define the geographic base from which the environmental survey comes. Use of the plant community results in an incorrect definition of the land base.

There is an analogy between the definitions of the habitat of a species population and the habitat of a wildlife community. Habitat is the sum total of the abiotic and biotic conditions of the land base within which the population or community of animals occurs annually or seasonally (decades or longer). The boundary of the habitat of a species population is determined by the temporal fluxes (annual or temporal) in the use of geographic areas by species and seral changes within the areas. The habitat of a wildlife community is the environmental conditions of the geographic area defined by the community. The boundary of the community does not incorporate the full geographic extent of all species populations that comprise it--the community is defined by the spatial similarity of the occurrence of species rather than by the geographic limits of the distributions of species populations.

The question posed addressed the wildlife and fish resource from the perspective of several measures of quantity at two levels of generalization. Other questions and measures of the wildlife and fish resource are possible and would potentially identify different survey variables. We have summarized the variables included in habitat descriptions suggested in several other publications. The studies referenced in Tables 6.2 and 6.3 are intended as further examples and are not inclusive. Table 6.2 includes example survey variables for population-level questions defined from niche and biogeographic studies. Most of the variables in these studies relate to habitat characteristics. Table 6.3 includes examples of studies in which community was defined on the basis of animal occurrence and in which niche variables exclusively represent the characteristics of wildlife community habitat.

Table 6.2:
List of variables for the individual or population-level concerns

Theory	Citation	Variables
Niche	Rotenberry and Weins 1980	• Vegetation cover • Vertical and horizontal structure of vegetation • Environmental predictability
	Holmes 1981	• Plant species composition • Vegetation structure • Foraging strategy • Body size • Soil parameters • Topographic parameters
	Dueser and Shugart 1979	• Plant species composition • Abundance measure of competitors • Dispersion of understory • "Evergreenness" of overstory • Soil parameters • Tree stump diversity • Foliage height diversity
Island biogeography	Diamond 1975b	• Patch size • Patch shape • Distance between patches
	Game 1980	• Patch shape
	Fritz 1979	• Patch size • Distance between patches

Table 6.3:
List of variables for community-level concerns

Citation	Variables
Niche	
Botkin 1977	• Evapotranspiration • Light • Nutrient gradient • Temperature • Moisture
Schall and Pianka 1978	• Elevation • Relief • "Sunfall" • Average annual precipitation and temperature • Summer temperature • Frost-free days/year • Difference between summer and winter precipitation • Difference between normal January and normal July temperatures • Actual evapotranspiration
Turner 1981	• Temperature variability (seasonality)
Richardson and Lum 1980	• Twenty-one variables that address climate seasonality, productivity, topography
Kaiser *et al.* 1972	• Forest type • Origin of prevailing air masses • Summer temperature • Weather disturbances (no. of daylight hours with bright sunshine)
Matson 1982	• Mean annual precipitation • Mean annual temperature • Mean temperature range • Maximum elevation • Elevation range
James and Wamer 1982	• Tree density • Basal area • Size class distribution • Percent evergreen tree cover • Percent canopy cover
Fisher 1968	• Rainfall • Temperature
Island biogeography	
Hagmeier 1966 – Matson 1972	• Species occurrence
Armstrong 1977	• Species distribution • Physiography
Bock *et al.* 1978	• Species occurrence • Species abundance
Fisher 1968	• Species occurrence • Vegetation distribution
Kaiser *et al.* 1972	• Species distribution

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Appendix

Appendix:
Commonly used field data collection procedures and their application to ecological land surveys (complied by John L. Kansas, Beak Associates Consulting Ltd.)

Method	Species applicable	Overview of technique	Appropriate scale	Type of information gained	Advantages	Disadvantages	References
Aerial surveys	• Ungulates, semi-aquatic furbearers (beaver and muskrat), ground squirrels, raptors, waterfowl, colonial waterbirds, etc.	• Animals or indicators of their presence (e.g., beaver lodges, muskrat pushups, bird nests, etc.) recorded and georeferenced within map units, along with habitat activity, habitat information, etc. • Complete study area coverage or quadrat surveys usually flown by helicopter transect by fixed-wing aircraft	• 1:10 000 to 1:1 000 000	• Estimates of populations and carrying capacity • Some habitat use data obtainable, although sample sizes small compared with detailed ground surveys	• Large areas sampled quickly • Absolute numbers collected • Well suited to population trend monitoring • Provides overall perspective of study area from the air, which can greatly improve interpretations and reporting quality	• Single point-in-time measure of animal density and habitat use (especially limiting when assigning carrying capacities and/or importance values to map units) • Helicopter rental costs high • Can be difficult to accurately georeference sightings within map units at scales larger than about 1:30 000	• Ungulates: Boyd 1958; Calef and Heard 1980; Gasaway *et al.* 1986; Gill *et al.* 1983; Kufeld *et al.* 1980; Meagher 1978; Stelfox and McGillis 1977; Timmerman 1974 • Semi-aquatic furbearers; Schemnitz 1980; Todd 1978 • Raptors: Boeker 1970; Fuller and Mosher 1981; Grier *et al.* 1981; Roseneau 1972 • Waterfowl: Allen *et al.* 1978; Bellrose 1978; Eng 1986; Haramis *et al.* 1985; Kirby 1980; Posaphala *et al.* 1974 • Colonial waterbirds: Erwin 1980; Kadler and Drurg 1968; Kushlan 1979; Portnoy 1980
Pellet group counts	• Ungulates (especially deer, elk, and moose), hares, and rabbits	• Groups of pellets counted in a series of plots or along transect lines in fairly homogeneous habitat types within map units	• 1:5 000 to 1:250 000	• Relative use of map units/ habitats • Rough estimate of population levels of map units	• Relatively inexpensive for small study areas • Generates large sample sizes for statistical analyses • Collects data accumulated over extended time period (e.g., November-May)	• Mere presence of pellets does not indicate type of use (e.g., feeding vs. migration vs. bedding) • Not as effective for gregarious species with clumped distribution (e.g., caribou)	• Anderson *et al.* 1972; Freddy and Bowden 1983a and 1983b; Ryel 1971
Winter track counts	• Winter-active mammals (ungulates, carnivores, hares, squirrels, etc.)	• Fresh tracks crossing linear transects through map unit or habitat type recorded	• 1:1 000 to 1:1 000 000	• Relative use of map units/ habitats • Quantitative and qualitative measure of preference for forage, bedding, etc. • Assessments of behavioural reactions to anthropogenic habitat alterations/ disturbances	• Efficient means for wildlife biologists to get a feel for wildlife use of habitats • Allows detailed assessment of forage use, bedding, and reaction to disturbance • Allows indirect, objective measurement of use of habitat types (much less expensive than live capture/ biotelemetry studies) • Provides very detailed behavioural data	• Relatively labour intensive especially over large study areas • Difficult to representatively sample map unit, for large map units • Consistent and adequate snow cover often not predictable, leading to logistical and budget difficulties • No established way to link track density with animal density • Difficult for many staff to identify mammal tracks in snow • Use index based on a 1-to-4-d period (does not represent a range of winter weather conditions)	• Barrett 1983; Holroyd and Van Tighem 1983; Koford 1977; Penner 1976; Raine 1983; Smith and Cameron 1985

Appendix: (continued)

Method	Species applicable	Overview of technique	Appropriate scale	Type of information gained	Advantages	Disadvantages	References
Roadside surveys	• Ungulates, raptors, upland game birds, songbirds, herptiles	• Animals observed or heard at stops along roadsides recorded and georeferenced within map units/habitat types	• 1:10 000 to 1:100 000	• Relative abundance • Presence/ absence	• A large area can be sampled in a relatively short time • Well suited to monitoring trends in animal numbers • Relatively inexpensive	• The full range of habitats in a study area often not accessible by road • Sample sizes generally small, unless long stretches of road driven • Wildlife often attracted to roadsides because of ecotonal diversity and productivity (difficult to assess whether animals present because of the inherent qualities of the map unit/habitat type or because of the ecotone) • Heavy traffic interference	• Craighead and Craighead 1956; Fuller and Mosher 1986; Holroyd and Van Tighem 1983; Kosicky *et al.* 1952; Riney 1982
Biotelemetry monitoring (conventional)	• Most large and medium-sized mammals • Birds, reptiles	• Live-capture, immobilization, and radiotransmitter instrumentation (collars, ear tags, implants, leg mounts) • Animal locations georeferenced at regular intervals, along with habitat information (ground locations accurate to ±100 m or less if signal walked in on; aerial locations accurate to ±100-300 m • Signs of resource use (scats, diggings, browse use, beds, etc.) quantified at or near the radiolocation sites	• 1:5 000 to 1:250 000	• Detailed to very detailed data on resource use for map units, habitat types, or broader home range (depending on manpower and resource allotments)	• If manpower and financial resources adequate, can provide considerable data on relative use of map units and resource attributes • Allows simultaneous assessment of animal occurrence and type of use • Necessary technique for species that are difficult to observe directly or through interpretation of signs (e.g., bears) • Can generate very large samples that are highly accurate • Provides good random data on habitat preferences	• High manpower and disbursement costs associated with capture and followup monitoring of animals • Multiyear studies usually required • Some degree of inaccuracy usually associated with radiolocations through triangulation (important when trying to link locations to large scale map units or plant associations)	• Hamilton and Archibald 1985; Hegdal and Colvin 1986; Kansas *et al.* 1989
Satellite telemetry	• Normally large and medium-sized mammals	• Same as for biotelemetry monitoring but data points generated by satellite	• 1:50 000 to 1:250 000	• Many data points (up to three locations per day)	• Large point data sets • Receive data independent of poor weather • Study animals located regardless of distance travelled • More cost effective	• Locational accuracy is relatively low (200-1000 m) for evaluating habitat preferences	• Fancy *et al.* 1988; Craighead and Craighead 1987; Curatolo 1986

Appendix: (continued)

Method	Species applicable	Overview of technique	Appropriate scale	Type of information gained	Advantages	Disadvantages	References
Random (incidental) observations	• All diurnal or crepuscular mammals, birds, and herptiles	• Animal locations and habitat associations recorded in conjunction with other research or inventory activities	• 1:5 000 to 1:500 000	• Confirmation of presence/absence and breeding status of species • Some basic information on trends in habitat use	• Most applicable to multiple species assessments in which species lists are generated for different life forms or broad habitat types • Can help to confirm the presence/absence of endangered, threatened, or vulnerable species within study areas or vegetation types, which can aid planners and managers in land use prescription	• Observations tend to be biased towards those routes and areas that are most commonly travelled or visited, which can lead to biases in interpreting wildlife/habitat relationships • Unless random data collection is well-structured, the data are often not used for subsequent analysis, and the field effort expended is wasted; for habitat-use assessments, incidental observations should only be collected for a selected group of species	• No references
Small mammal trapping	• Small rodents and insectivores	• Live, pitfall, or snap traps laid out along transects or in grids • Live-trapped animals individually marked and released; recaptures of individuals monitored, and formulas used to estimate population size (based on rates of recapture of previously marked animals) • Snap-trapped animals recorded by species and an index of the number of animals of a given species trapped per trap-night calculated • Traplines established in a variety of map units and/or habitat types	• 1:5 000 to 1:50 000 • Small mammal trapping data usually collected at the vegetation type or plant association level of detail	• Snap and pitfall trapping provides presence/absence data and an index of relative use of map units and habitat types • Live trapping and mark/recapture provide estimates of population and carrying capacity • Both techniques allow the determination of small mammal associations (i.e., commonly recurring groups of small mammal species that use particular habitat types)	• Because of the shy, secretive nature of small mammals, trapping is the only reliable technique to monitor small mammal abundance and habitat use • An estimate of the abundance of the small mammals by habitat allows an indirect evaluation of habitat importance to carnivores and raptors	• Labour intensive (traps must be checked regularly) • Precise population estimates (esp. through live-trapping may involve prohibitive manpower costs • Possible skewed habitat preferences and population estimates due to unequal trappability of species (trap "shyness" of some species)	• Anderson *et al.* 1977; Call 1986; Kepner 1978; Mosby 1963; and Seber 1973

Appendix: (continued)

Method	Species applicable	Overview of technique	Appropriate scale	Type of information gained	Advantages	Disadvantages	References
Breeding bird surveys	• Songbirds (Order Passeriformes), swifts, nighthawks, hummingbirds, kingfishers, and woodpeckers	• Spot mapping (grids): censuses of an area of specified size in a homogeneous habitat type or land unit; area gridded to form survey base; observer walks systematically through the grid, recording the position of all birds seen or heard • Transects: counting birds seen or heard on one side or both sides of a line walked through specific habitat types; width of transect predefined or distance of bird from transect estimated • Point count: network of points regularly distributed throughout habitat types; observer stands at each point for 20 minutes during each morning and records all birds seen or heard; each point censused twice during breeding season; index of bird use calculated based on numbers and types of observations (e.g., singing male, occupied nest, etc.)	• 1:5 000 to 1:50 000	• During breeding season, absolute and relative densities of territorial male birds per habitat type (absolute densities best achieved by spot mapping; for most species, however, rarely physically possible or economically feasible)	• Provides managers with index of overall habitat diversity and potential for wildlife production • Land units with high breeding bird diversity usually also productive for other species groups (esp. small mammals, raptors, and carnivores)	• Labour intensive, requiring highly specialized biologists • Requires accurate mapping of habitat type or land unit boundaries and precise detection of birds seen or heard relative to these boundaries	• DeGraff and Evans 1979; Emlen 1971, 1977; Franzeb 1977; Ralph and Scott 1981; Reynolds *et al.* 1980; Robbins 1978; Van Tighem and Gyug 1984; Verner 1985

Appendix: (continued)

Method	Species applicable	Overview of technique	Appropriate scale	Type of information gained	Advantages	Disadvantages	References
Forage availability use surveys	• Most medium-sized to large mammals, esp. ungulates and bears	• Forage availability can be absolute value (e.g., kg/ha) or forage classes corresponding to range of values (e.g., class 1 = X-Y kg/ha lichen); data collected on % cover or biomass of forage types or key forage species per habitat type or land unit; can often be derived from vegetation data of the ELC phase • Forage use can be measured directly by quantifying "clipping" of vegetation or indirectly by fecal analysis (both provide index of importance of particular plants or plant communities as forage items); preference or avoidance of species assessed by simultaneous measurement of availability and use along same transects or in same plots (statistical tests applied to confirm preference/avoidance)	• 1:5 000 to 1:50 000	• Food item importance values • Percent occurrence of key forage species by land unit • Relative availability of forage groupings by land unit • Relative importance of land units for forage production	• Can be conducted in conjunction with the rest of the ELC fieldwork • Detailed long-term data on forage use from other areas in an ecoregion often can be extrapolated to a particular study area	• Forage use assessments very labour intensive • Single-year measurements of forage use may not represent actual forage importance because of year-to-year climate variations	• Demarchi and Harcombe 1983; Hadden *et al.* 1986; Usher and Kansas 1987; Westworth *et al.* 1983

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